ELEMENTS

OF

NATURAL PHILOSOPHY,

WITH

QUESTIONS FOR REVIEW;

ILLUSTRATED BY

One Hundred and Eighty-eight Engravings;

FOR

THE USE OF SCHOOLS.

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Author of Elements of Chemistry, Elements of Plane and Solid Geometry, Popular Lessons in Astronomy, Exercises in Algebra, Arithmetic, &c.

SECOND EDITION, STEREOTYPED.

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PREFACE

TO THE FIRST EDITION

The general want of a suitable text-book on Natural Philosophy, adapted to young pupils, and, at the same time, to the progress of instruction in this country, has, for a long time past, been the subject of complaint with many of the most experienced teachers. In the following treatise, the author has made an attempt, so far as his abilities permitted, to supply this deficiency. He has, for this reason, endeavored not only to preserve his work from some of the gross errors, with which it is common to find elementary treatises on this science charged, but has enlarged it also with the most recent discoveries in electricity, galvanism, and magnetism. The authorities, and the sources from which he has drawn, have been carefully indicated; and the subjects on which the opinions of philosophers are divided, treated of in a manner to leave both teacher and pupil at liberty to adhere either to one or the other hypothesis. As regards the general plan and arrangement of the work, it will suffice to say, that the *inductive method* has been pursued, as far as it was practicable in a treatise of this nature. The whole is divided into ten Chapters, treating separately of the General Properties of Matter, of the Phenomena of Cohesion and Adhesion, of the Laws of Motion, of Hydrostatics and Aërostatics, of the Mechanical Properties of the Atmosphere, of Heat, Light, Electricity, Galvanism, and Magnetism. Each

Chapter is again divided into Sections, which are numbered, and consist of short sentences, for the sake of being more easily referred to, and to assist the memory of young pupils. The mathematical part has been separated from the text, and is thrown into the notes, not to interrupt the progress of those who are not yet familiar with mathematical reasoning. The Appendix contains nothing but Exercises for the pupils, which are divided into as many Chapters and Sections as the text; each Chapter referring to the same Chapter in the text, and each Section to that Section of the book which is preceded by the same number.

The astronomical part has been omitted, for the obvious reason of its making no part of Natural Philosophy. Astronomy is a science sufficiently important of itself to be treated of separately, as has been done by authors of distinction, whose works are already extensively introduced into common schools. The study of Astronomy, when united to that of Natural Philosophy, tends, in most cases, only to divide the attention of the learner, and to impede his progress. It is more intimately connected with Mathematics, and forms a far better sequel to Geometry, than any branch of the natural sciences.

Having thus brought his treatise on Natural Philosophy to its proper limits, the author intends to have it followed by an elementary treatise on Chemistry, which will be executed on the same plan, and form a necessary sequel to this work.

Boston, March 28, 1832.

PREFACE

TO THE STEREOTYPE EDITION.

At the suggestion of many intelligent instructors, the First, Second, and Third Chapters have undergone considerable alterations, to adapt the work to the capacity of young pupils. The Fourth Chapter is entirely new, and treats of Mechanical Powers. The remaining Chapters are but little modified. To reduce the price of the work, it appears, in this edition, in a more condensed form. Instead of the Appendix of the first edition, each Chapter is followed by a Recapitulation, containing questions for the exercise of the pupils.

Boston, January 25, 1835.

DIRECTIONS TO TEACHERS.

To every Section of the book there is a question in the Recapitulation, preceded by the same sectional number as that of the text. The sentences in italics are to be committed to memory, and constitute the answers to the questions in the Recapitulation, which are likewise printed in italics.

The questions which are printed in smaller type, refer to the remarks in the text, which are intended for more advanced pupils, and may be omitted until reviewing the book.

The questions in the notes refer to the mathematical part, contained in the notes to the text. They are to be required only of those pupils who have had some instruction in mathematics. They are all of so simple a nature, that any one who has acquainted himself with the elements of geometry will be ready to answer them.

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NATURAL PHILOSOPHY.

CHAPTER I.

OBJECTS AND DEFINITION OF NATURAL PHILOSOPHY.

GENERAL PROPERTIES OF BODIES.

§ 1. As far as the material world, in which we are placed, is perceptible by our senses, it consists of things, and of changes to which these things are constantly subjected.

§ 2. Natural Philosophy is the science of visible things, and has for its object the investigation of the laws to which they are subjected.

§ 3. Among our senses there is but *one* which informs us directly of the existence of bodies; this is the sense of *touch;* hence we may say *that a body is a tangible thing*.

The organ of sight does not always convey a direct proof of the existence of a body: the spherical form of the sky, the images in looking-glasses, &c., are only *appearances* of things, but have, of themselves, no material existence. With regard to the organs of taste, smelling and hearing, the testimonies of these senses are so vague and contradictory, that we cannot rely upon them with any degree of certainty. Thus many bodies, such as silex (the principal ingredient of glass), atmospheric air, most of the gases, and many of the metals, are entirely tasteless and inodorous; and yet each of them has an independent material existence.—*Sound* emanates from bodies only under certain circumstances, so that nothing is more possible for us, than to be in the immediate neighborhood of a sonorous body, without having the least indication of it through the sense of hearing.

§ 4. There are certain properties which are common to all bodies, and others which belong to some of them exclusively. To the former are reckoned the two most universal properties of things—*magnitude* and *impenetrability*.

Magnitude is the extension of a body, or the space which it apparently fills, and is by some philosophers also called its *volume;* and the bulk of matter which it contains is called its *mass. Impenetrability is that general property of bodies, which prevents one body from entering the space already occupied by another.*

It is certain that we cannot imagine a body ever so small without having at least some magnitude; nay, this is so much a condition of tangible things, that without it we should absolutely remain ignorant of them, since they could not possibly affect our senses.

In reference to the impenetrability of bodies, we would observe, that by it we do not mean, that one body may not be made to occupy a *portion* of the space formerly filled by another. On the contrary, phenomena of this kind are of such frequent occurrence, that they may be witnessed every day.—In compressing a sponge, or a piece of India rubber, we certainly force these bodies to occupy less space than before, and therefore fill, with our hands, a *portion* of the space formerly filled by them; but there is no power in nature which can so far compress a body, as entirely to deprive it of magnitude, because this would amount to a total annihilation of it; and it is this resistance to a total annihilation of *magnitude* which has properly received the name of *impenetrability.*

§ 5. *Matter* is the universal term for the infinite variety of bodies, independent of form, magnitude or quality. Hence we say, in the abstract, *Matter* is that *which fills space.*

In the course of this treatise, we shall often use the terms *time* and *space;* but we would warn the pupils never to forget that time and space are not *things* of themselves, but merely certain conditions of our perceiving them, which we shall now explain. All phenomena in nature cannot occur *at once:* they follow each other with a succession of intervals, the length or duration of which we are capable of comparing and measuring. This constitutes our idea of *time.* Neither is it possible for us to imagine two bodies to be, at the same time, in the same place. Each body exists within certain limits inaccessible to others, the extent of which, however, is subject to variation, and is, therefore, again capable of being compared and measured. This constitutes the idea of *space.*

DIVISIBILITY, POROSITY, DENSITY, COMPRESSIBILITY, EXPANSIBILITY, MOBILITY, AND ELASTICITY OF BODIES.

§ 6. Besides the two universal properties of bodies, of which we have spoken in the preceding section, there are yet seven others, which, we know from experience, are, in a greater or lesser degree, common to all bodies; these are, *divisibility*, *porosity*, *density*, *compressibility*, *expansibility*, *mobility*, and *elasticity*.

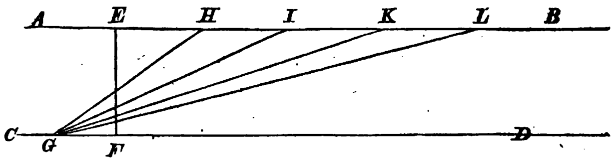
We shall now proceed to describe each of these properties separately.

§ 7. *Divisibility.* Experience and observation teach us that all bodies, even the hardest or most compact of them, may, by the application of some exterior force, be separated into two or more parts: each of these may again be subdivided into two or several lesser parts, which, in their turn, may be separated into parts still more minute; and there exists, in the mind, no actual limit beyond which this gradual subdivision may not be carried. This capacity of being divided into smaller and smaller parts, is termed the *divisibility of bodies, or of matter in general.**

* We may easily prove, geometrically, that space is divisible *ad infinitum;* that is, we may prove that there is no absolute limit to the subdivision of any definite magnitude of space. The same, however, can hardly be supposed to be the case with a fixed portion of *matter;* for, although the division of some substances may be carried to an astonishing minuteness, yet the particles thus obtained become finally so small, that their further division becomes, at least *mechanically*, impossible:

The following easy demonstration will establish the first part of our assertion.

Fig. 1.



Let AB, CD, be two indefinite straight lines, which, we will suppose, are parallel to each other. Between these two lines we will suppose the line EF to be drawn perpendicular to CD. From E, in the direction from E to B, take the distances EH, HI, IK, KL, &c.,

Instances of extreme divisibility are daily furnished by many processes in the mechanic arts, such as pounding, wiredrawing, plating, gilding, &c. Very remarkable, in this respect, is the extreme minuteness to which the particles of a number of substances may be reduced by some of these operations. Dr. Wollaston has succeeded to draw platinum into wire of not more than one eighteen thousandth part of an inch in thickness. A piece of gold sufficient to cover the one hundredth part of an inch of this wire, is not more than the 864 millionth part of an ounce; and, by the aid of a microscope, it is possible to carry this division still farther, to the 432 billionth part of an ounce. A gold-beater can hammer out one tenth of a grain of gold into 37 square feet surface; and, according to Réaumur, one single grain of gold may be drawn into a piece of wire 600 feet long; and 38 grains of the same metal would be sufficient to cover a piece of silver wire upwards of 1000 miles in length. (See Chemistry, Chapter IV., on Metals.) Nature furnishes us with still more striking instances of the extreme minuteness to which the division of matter may be carried. The wings of some of the insects (50,000 of which would not have a quarter of an inch in thickness), the dust on the wings of butterflies, the eyes of bees, the innumerable class of animalculæ, so small that they are not perceptible without a microscope, and yet endowed with all the organization of superior animals, are ample proofs of this assertion.

§ 8. *Porosity.* The space which bodies occupy is not throughout filled with their own substance. In a piece of wood, for instance, there are places which, at least, are not filled with particles of wood. These are called *interstices* or *pores*. Now, as the same property has been more or less observed in all bodies, as far as we have been able to examine them, we may safely conclude, that all bodies have pores, or that porosity is a general property of bodies.

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all equal to one another; and from any point, G, on this side of the line EF, draw the straight lines GH, GI, GK, GL, &c. These lines will divide the line EF successively into smaller and smaller parts; and as there is no limit to the number of equal distances which may be taken upon the indefinite line EB, there can be none to the number of parts which may thus be cut off from the line EF: further, as CD is parallel to AB, it follows that none of the lines GH, GI, GK, &c., can ever coincide with the line CD, or with one another; consequently, there is no assignable limit to the minuteness of the parts into which the line EF may be divided. Now, as every straight line, consequently, also, the line EF, represents a dimension of space, it follows that every dimension of it, and, therefore, space itself, may be divided in the same manner. Hence we are correct in saying *space itself is divisible ad infinitum.*

It is not necessary to suppose that the pores of matter are *vacui*, that is, entirely *void of matter*. When water or other fluids enter the pores of bodies, it may be by expelling another substance previously contained in them. (This is done, for instance, when a sponge is filled with water; the air contained in it is then expelled.)

Remark. The pores of bodies, and the cellular texture of plants and animals, explain the influence of the atmosphere upon them, the operation of salves, plasters, &c.; for, unless the skins or coverings of animals were provided with pores, these salves could never penetrate, nor could the dampness or dryness of the atmosphere have such an immediate influence upon us: perspiration would be entirely impossible, and the enduring of heat be rendered painful and dangerous.

§ 9. *Density.* If the whole volume of a body were entirely filled with its own matter, that is, if there were no interstices, it would be *perfectly dense.* As there is no such body in nature, *we call a body more dense in comparison with another, when it has fewer interstices, or, which is the same thing, when it contains a greater quantity of matter in the same space.*

Thus a piece of wood is said to be less dense than a piece of iron of the same magnitude, because it contains less matter in the same space; but wood is denser than atmospheric air, because it contains more matter in the same space.

§ 10. *Compressibility.* Experience teaches us that all bodies may, by an adequate exterior force, be compelled to occupy less space without diminishing in matter or substance. This property, which is owing to the porosity of bodies, is termed *compressibility.*

Fig. 2.

A simple experiment of this kind may be made by the compression of atmospheric air, in a cylindrical barrel, AC (see the figure), by means of a piston, E, being moved air-tight by the rod B*f*. It is evident that when the piston is pushed down to the middle of AC, the air in the barrel will be compressed to *one half* its former volume; if the piston is moved down to one fourth of EC, the compression is carried to one fourth of the volume, and so on. And as the particles of air in the barrel are brought nearer each other in proportion as the piston is moved down into the barrel, the number and magnitude of interstices must diminish accordingly.

Remark. A body without pores (a perfectly dense body) would be incompressible; because, as we had

occasion to remark before (§ 4), one body cannot enter upon the substance of another and fill the space already occupied. In our experiment, therefore, the piston does not fill the space occupied by the air, but merely *displaces* a portion of it by forcing it into a smaller space.

§ 11. *Expansibility*. Besides the capacity of bodies, under certain circumstances, to occupy *less* space, most of them may also be made to occupy *more*, which property has received the name of *expansibility*.

As an instance, we may take the above-described experiment. When the piston, E (see Fig. 2. page 17), has been forced down near the bottom, C, and is then left free, it will immediately be pushed up again; and this will be occasioned by the rapid *expansion* of the compressed air in the barrel. Now, although this property does more especially belong to atmospheric air and the gases, we shall soon learn that no body in nature is entirely destitute of it; nay, that most substances may, through the influence of heat and other circumstances, be brought to assume the gaseous form.

§ 12. *Mobility*. In animated nature, every body has the power of changing its place, which faculty is termed *locomotion*. Now, although this power is denied to plants and minerals, yet every day's observation shows us that they may at least be made to change their places by the application of some *external* force. A ball may be moved by a stroke of the hand or foot; a ship, though, of itself, motionless, sails from one place to another by the power of the wind; projectiles are thrown by the force of gunpowder; boats and machines are moved by the application of steam, &c. This universal capacity of bodies of changing their places or relative positions, is termed the *mobility* of bodies. The act itself, of proceeding from one place to another, is called *motion*.

The capacity for motion does not only belong to the bodies themselves, but is also a property of their *particles*. This is manifest by the capacity which they have to change their relative position; for, without the mobility of particles, there could neither be compression nor expansion, nor any other change in the form of bodies.

§ 13. *Elasticity*. There are bodies which are capable of changing their forms, when some interior force is applied to them; resuming, however, their former shape as soon as that power ceases to operate. This property, which all bodies

possess in a greater or less degree, is known by the name of *elasticity*.

EXAMPLES. An ivory ball, which is striking upon a firm plane, becomes indented at the place where it comes in contact; but immediately after resumes its former round shape. A piece of India rubber, whether compressed or stretched by the hand, resumes its former shape as soon as it is left to itself. Even the experiment alluded to in § 11 is a proof that the air is elastic; for, after being compressed in the barrel, it resumes its former extension when the piston is left free. But we shall presently have occasion to say more on this subject, especially when treating of acoustics.

INFINITE VARIETY IN THE MATERIAL COMPOSITION OF BODIES, ATOMS, MOLECULES AND PARTICLES OF MATTER.

§ 14. Our senses inform us that all bodies do not exhibit the same properties, or, at least, do not affect us in the same manner. Who can number the infinite variety in the material composition of bodies? the variety in color, taste, elasticity and form? the numberless ways in which they affect our sense of touch? There are not two bodies in nature exactly of the same form, color, or taste, &c. Even in the same body, as, for instance, in granite, we discover, often, parts of a different nature. Hence arise the different appellations of bodies; the endless catalogue of animals, plants and minerals. Bodies which resemble each other in some of their essential qualities, are said to belong to the same *genus* or family. Bodies which are formed of the same substance are said to be *homogeneous*, and those which are composed of different materials are said to be *heterogeneous** substances.

§ 15. To account for the infinite variety of substances, many philosophers suppose, that all bodies are originally composed of particles unchangeable and indivisible, and so small as altogether to elude our senses. These ultimate

* The words *homogeneous* and *heterogeneous* are taken from the Greek, and signify, *of the same kind*, and *of different kinds*, respectively.

particles they call *atoms;* and on their relative magnitude, form, position, and distance from each other, depend, in their opinion, the shape, texture, color, taste, &c., in short, all the properties of bodies which are the subject of philosophical inquiry.

This theory, however plausible, is yet far from being satisfactory; but, then, it is more than probable that we shall never be able to discover the ultimate cause of any of the various phenomena exhibited by nature. Besides, the above theory has lately gained so much ground with the most distinguished philosophers of the age, and accords so perfectly with all modern discoveries in chemistry and crystallization, that it is at least a powerful aid to the imagination, if not of real advantage to science. (See Chemistry, Introduction, and Chapter IV., on Crystallography.)

§ 16. According to the above atomistic theory, the smallest parts obtained by the mechanical division of bodies, although they may absolutely be so small as to escape sensible observation, are yet composed of several atoms. All such parts, therefore, are called *molecules;* and by *particles* we designate such parts of matter as have yet a perceptible magnitude.

ATTRACTION, ADHESION, COHESION, TERRESTRIAL GRAVITY, GRAVITATION.

§ 17. When particles obtained by any kind of mechanical division are brought sufficiently near each other, they evince, in most cases, a disposition to unite again; and, in general, whenever two well-polished surfaces of any kind are brought in contact, they adhere to each other with considerable force.

Example. Two drops of water unite in one as soon as they are brought in contact; two well-polished glass plates, or a glass and a copper plate, or two pieces of wood, when brought in close contact, require a considerable force to be separated. Pieces of wood, paper, or glass, immersed in water, and then withdrawn, are found to be *wet;* and in a similar manner do water and many other fluids enter the interstices of wood, paper, sugar and other porous substances.

To account for these phenomena, we are naturally led to suppose that there is some force or power, which compels bodies to

this mutual approach. This invisible power, which, as far as our observation and experience go, is diffused throughout nature, is termed *attraction;* and if it is manifested in contact between two apparently heterogeneous substances (as in the examples just mentioned), it is called the *attraction of adhesion*, or *adhesive attraction*, to distinguish it from another kind, with which we shall presently become acquainted.

§ 18. The power of attraction, which is manifested in the adherence of one body to another, exists in a still higher degree between the particles of *the same substance*.

EXAMPLE. A board is not easily divided into parts; but the whole board may be moved with little effort. A piece of iron can only with extreme difficulty be separated from a block; whereas the block itself may be removed from its place without much exertion. In general, whenever we wish to give a peculiar form to wood, iron, brass, silver, ivory, glass, marble, &c., we meet with a certain degree of resistance. This, together with the force which is required to effect the mechanical division of bodies, convinces us of the existence of a certain power by which they are held together, and in their relative positions. This is another species of attraction, which, to distinguish it from the one described in the last paragraph, is termed the *attraction of cohesion*.

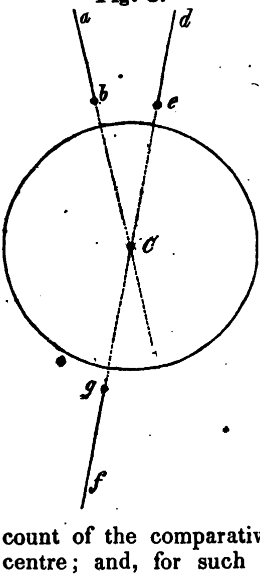
Cohesive attraction, therefore, is manifested between the particles *of the same substance*, whilst *adhesive* attraction is that which operates between heterogeneous substances.

§ 19. Another still more remarkable kind of attraction is evinced in the disposition which all bodies have to descend, in straight lines, to the surface of the earth. Examples of this kind are so numerous, and of such daily occurrence, that it is hardly necessary to recur to them. Any heavy body,—a piece of marble, lead or stone,—suspended by a string, will stretch that string in a straight line; or, when placed upon a flat surface, will exercise upon it a considerable pressure. When the string is cut, or the surface removed, the body will descend to the earth in a straight line. This phenomenon is called the *falling* of bodies. As it does not only occur at one place, but may be repeated wherever we please, we cannot account for it in any other way, than by attributing to the earth itself the power of attracting bodies. This attraction, which is no longer confined to the contact, but impels all free bodies to descend in a direct line to the surface of the earth, or causes them to exercise pressure on all bodies which prevent them from following that impulse, is called the *attraction of gravity*.

§ 20. The direction in which a falling body approaches the surface of the earth, is termed a *vertical* or *plumb line.* This line is every where perpendicular to the surface of the earth, and may be exhibited by any heavy substance, suspended by a string. Lines or planes at right angles with the direction of gravity, are said to be *horizontal. Inclined* planes form oblique angles with the direction of gravity. Hills and mountains differ from planes, inasmuch as their surfaces form oblique angles with the direction of gravity.

§ 21. *Definition of the Terms* Vertical *and* Horizontal. Since the earth is a sphere, or, at least, *approximates*, in its shape, a perfectly round body, the direction of gravity must every where go through its centre. Thus if C (Fig. 3) represents the centre of the earth, and *ab*, *de*, the directions of two falling bodies, these two lines would, if sufficiently far extended, meet in the centre of the earth. Hence two plumb lines, suspended at two different places, are not parallel, but are inclined to each other by an angle, which becomes larger in proportion to the distance of the two places. Finally, at two opposite positions on our globe, represented in the figure by *e* and *g*, the directions of gravity *de*, *fg*, will be diametrically opposite to each other. But at small distances (such as do not exceed 100 feet), the inclination of two plumb lines is scarcely perceptible, even with the nicest mathematical instruments, on account of the comparative great remoteness of the earth's centre; and, for such distances, therefore, we consider these lines as parallel.

Fig. 3.



§ 22. *Definition of Weight.* The pressure which a body exercises upon a horizontal plane which prevents it from falling, or the degree of force with which it pulls a string by which it is suspended, is called its *absolute weight.*

There is a great difference between gravity and weight.

Gravity is in all substances alike; that is, all substances are equally, and in the same direction, attracted to the centre of the earth. But, all particles of matter being alike attracted, it follows that the pressure resulting from them, is in proportion to their number; that is, *the absolute weight of bodies is in proportion to their masses.*

A feather and a piece of lead are both equally attracted by gravity, and would, if there were no resistance of air, fall to the ground in the same time; but they exercise very unequal pressures on a horizontal plane. The lead contains, in the same space, a greater quantity, or more particles of matter, than the feather; and, each particle receiving an impulse in the direction of gravity, the pressure resulting from the lead will be much greater than that of the feather. What we have said of two heterogeneous substances, would equally apply to two bodies of the same substance, provided they contained unequal masses, the largest bulk of matter always exercising the greatest pressure.

§ 23. In order to determine the absolute weight of bodies, we make use of a certain weight as unity of measure. This may be a pound, an ounce, a drachm, &c.

For different bodies we use different units of measure, according to the degree of exactness required. Thus we have avoirdupois weight, troy weight, apothecary's weight, &c. When we say a body weighs three pounds, we mean that its pressure upon a horizontal plane is equal to the united pressure of three units of measure (here pounds).

The balance, and other instruments for determining the weight of bodies, will be spoken of in Chapter IV.

§ 24. *Specific Gravity.* It is often of the greatest importance to know which of two bodies of the same volume, exercises the greatest pressure on a horizontal plane; or, which amounts to the same, which of two bodies of the same dimensions has the greatest mass, and, consequently, also, the greatest density. (Sec. 1.) To answer this question, we must either know which of two bodies, of the same volume, has the *larger weight*, or which of two bodies of the same weight has the *smaller volume.* In either case, we determine the *specific gravity* of these bodies; by which is meant *the absolute weight of one body compared to that of another of the same volume.* Hence, *the specific gravities of bodies are in direct proportion to their absolute weight, and inversely as their cubic contents;* that is, among bodies of equal volume, that is specifically heaviest whose absolute

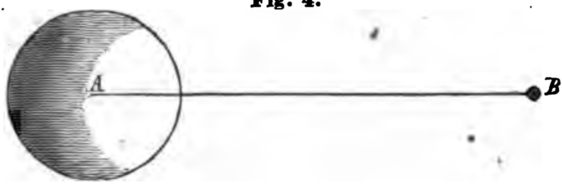
weight is greatest; and of bodies whose absolute weights are equal, the specific gravity of that is greatest whose volume is smallest.

To give an Example. Suppose two bodies, A and B, weigh, A 5 lbs. and B 10 lbs., and that both have exactly the same volume; then the specific gravity of the body B will be double that of the body A. Again, let us suppose that both bodies have the same weight, say 5 lbs., but that the body A is only one half as large as the body B; then the specific gravity of the body A will be double that of the body B.

To determine the specific gravities of bodies, we generally compare their weights with that of an equal volume of distilled water. But the process by which this is done being founded on the laws of hydrostatics, we must refer the learner to Chapter V., where we shall speak of the *Pressure and Equilibrium of Liquids.*

§ 25. The attraction of gravity, as far as we have been able to trace its cause, is not located in any particular portion of the earth, although its effects are such as would be produced by a single attracting point, situated in the earth's centre. On the contrary, it can be proved, by the single force of mathematical reasoning, and even by experiments (as we shall presently see), that every particle of matter is imbued with the power of attracting others; so that, when a body is thrown up into the atmosphere, it is not only attracted by the earth, but the body does also, in its turn, attract the earth. The reason why this *mutual* attraction does not come within the sphere of our immediate observation, will be easily comprehended from the following course of reasoning.

Fig. 4.



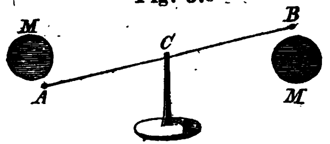
Let A and B be two bodies of different magnitudes, and, for the sake of simplicity, let us suppose that the body A has a thousand times the magnitude and bulk of matter of the body B. It is evident that the body A will have 1000 times as many attracting particles as B, and, consequently, that

the effect produced by their united action upon B, will be 1000 times greater than that which B produces upon A. Hence, if the whole distance between A and B be divided into 1001 parts, we may conclude that the attraction of the body A will have moved the body B through 1000 of these parts, when that of B will have moved A only through one of them. The larger body, A, therefore, will only move $\frac{1}{1001}$ of the distance of the body B.

Let us apply this example to our theory of terrestrial gravity:—The bulk of our earth is, at least, one quatrillion, that is, one thousand million million times larger than the largest body which has ever been observed to fall through our atmosphere. Now, supposing such a body to descend through a height of 1000 feet; then, if the earth is not solicited by any other power, it ought to move towards that body by $\frac{1000}{100000000000000}$ part of a foot, which is but little more than the one hundred billionth part of an inch; and this motion, of course, could not be perceived by our senses.

What we have said in relation to the power of attraction which is inherent *in each particle of matter*, although established by the simple force of mathematical reasoning, has actually been proved by an *experiment* of Mr. Cavendish, which we are now about to describe.

Fig. 5.



Place two heavy globes of lead, M, M (see Fig. 5), of about a foot and a half in diameter, at a short distance from each other; between them, on a very sharp point, suspend a thin rod, AB, which must be balanced on its centre, and provided at its ends with two small metallic balls, A, B. The position of the rod must be such that the attraction of the two balls may have a tendency to turn the rod the same way. As soon as this is done, a manifest effect will be produced on the rod, by the attraction of the two globes, inclining the rod to turn on its axis, C.

(In this experiment, great care should be taken to avoid all magnetic substances, and to prevent, as much as possible, all friction at the point C; for which reason, the rod, AB, ought to move on a sharp piece of diamond, or some other hard substance.)

The questions might here be asked, why we do not oftener perceive the mutual attraction which exists between two bodies

placed at certain distances from each other; why stones and rocks do not move towards each other, &c. To these questions we should have to make no other reply than that the attraction of the earth is so much stronger than that which exists between any two bodies on its surface, that it is impossible for us to discern the nice operations of the latter, when compared to the striking effects of the former.

§ 26. *Universal Gravitation.* The principle of mutual attraction, which exists between any two particles of matter, is not solely confined to our globe. We know, from astronomy, that it equally extends to the sun and the planets in our system, and to the most distant spheres and worlds. Attraction, considered in this sense, is termed *universal gravitation.* Sir Isaac Newton was the first who taught that the revolution of the moon round the earth was produced by the attraction of gravitation from our earth, or, in other words, that the moon *gravitated towards us.* In the same manner do the earth and all the planets gravitate towards the sun; and the sun, with all its planets, may gravitate towards a still larger body; and it is highly probable that the whole universe gravitates in this manner towards a common centre. It is this universal principle which gives and preserves to each heavenly body its form and orbit, which keeps its particles together, so that not a grain of dust can escape from its surface, which unites the whole of God's creation into one immeasurable whole, and brings order and harmony into the motion of the most distant spheres: the Divine Author need but destroy this invisible link, and nature sinks into chaos.

REMARK. Besides the three kinds of attraction which we have just considered, there are yet three deserving our particular attention. These are *chemical*, *electric* and *magnetic* attraction. Of the first of these we shall speak in the Second Chapter, and the laws of the second and third we shall investigate when treating of Magnetism and Electricity

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AGGREGATE FORMS OF BODIES.

§ 27. Among the infinite variety of forms which matter exhibits to our senses, there are three which are most palpa-

ble and deserving of our immediate notice. Some bodies are more easily divided in one direction than another, and offer, in general, considerable resistance to division or separation. These bodies, in most cases, have a peculiar *texture;* that is, their particles are arranged after a certain order, and are designated by the name of *solids;* and the form which they exhibit is called the *solid form*, or *solidity*.

As examples, we will mention most of the metals, wood, glass, ivory, marble, lime, chalk, &c. All these bodies, when fractured, exhibit a peculiar arrangement of their particles, and are generally more easily divided in one direction than another. A piece of wood, for instance, is more easily broken against the grain, than following the direction of its fibres; a piece of glass is more easily fractured by a stroke perpendicular to its length than by one applied to either extremity.

§ 28. The second important form of matter is exhibited by those bodies whose particles are with the greatest ease removed or separated. They seem to be destitute of any particular arrangement of their particles, and are, consequently, as easily divided in one direction as in another. These bodies are known by the name of *fluids*, and their form is termed the *fluid form*.

§ 29. The fluids themselves exhibit properties so different from each other, that they may again be divided into two distinct classes. To the first class belong those which are but very little compressible, and in minute quantities form spherical drops. These fluids are called *liquids*. To the second class are reckoned those which are possessed of qualities directly opposite to those which we have just named, viz. They are compressed with great facility; but are incapable of forming drops, and resume, after the compression ceases, their former volume. These fluids are termed *gases*, and form the properties just described. Their form is called the *elastic* or *gaseous* form.

Examples. The water, which surrounds more than three fourths of our globe, is a *liquid*, because it is compressible only with great difficulty, and only with very little diminution of volume; but in small quantities it forms drops. Oil, wine, cider, beer, vinegar, &c., are, for the same reasons, bodies which exhibit the liquid form. Our atmosphere, on the contrary, is a gaseous or elastic substance, because it may be easily compress-

ed, and reëstablishes its former volume when the compression ceases. Compare the experiment described in § 10 and § 11, pages 17 and 18. To the same class of bodies belong hydrogen, oxygen, nitrogen, and a variety of similar substances, together with steam, and all kinds of vapors.

§ 30. *Aggregate Forms.* The three principal forms of matter which we have just considered, and with regard to which all bodies are either *solid*, *liquid*, or *gaseous*,* are termed the three *aggregate forms*. From this, however, we must not infer that a body which appears to us only under *one* of these forms, is absolutely incapable of assuming another. Experience and daily observation inform us that solids and liquids become frequently transformed into elastic fluids, and gaseous substances become again liquid or solid.

Examples. Ice becomes *water*, and water *steam*, under the influence of certain degrees of heat; but steam may, by cooling, or in contact with a liquid, be again changed into water, which, by the act of freezing, is again converted into ice. We see, from this, that a body, under certain circumstances, may pass from the solid to the liquid, and thence to the gaseous state, whence it may be again reduced to the state of solidity. Nor does this property belong exclusively to any one substance; on the contrary, it seems to be a property common to all; nay, it is more than probable that there is not a body in nature entirely destitute of the capacity of changing its aggregate form.

§ 31. *Melting of Bodies.* We have observed, in the preceding section, that solid substances often become liquefied, especially when exposed to certain degrees of heat. This process is called the *melting* of bodies. Very few bodies indeed can resist the action of fire, or the heat produced by lenses or burning-glasses; not to mention the means which chemical and electrical apparatus furnish for the liquefaction of solids. This has led philosophers to suppose, that all bodies are, in their original state, fluid, whence they become solid through the loss of heat. In general, it appears that all matter has at first been in a fluid state; and we see yet, every day, in all three kingdoms of nature, solid substances form themselves out of fluids; and the round shape of the heavenly bodies themselves seems to agree with this supposition.

* Gaseous bodies are also called *aeriform*, from their resemblance to air, the principal elastic fluid in nature.

§ 32. Those fluids which obey the laws of gravity, and whose weight, therefore, can be ascertained, are called *ponderable*. To these belong all gaseous (aeriform) fluids, steam, and vapors. But there are other fluids, viz. light, caloric, electric and magnetic matter, which are either not at all, or, at least, so little affected by gravity, as entirely to escape our observation; wherefore they are called *imponderable* substances.

As their theory is very complicated, we shall treat of them separately in the course of this work, devoting to each a separate chapter for the investigation of its properties.

Remark. Some philosophers (particularly in Germany) are willing to consider the imponderable substances as exhibiting a peculiar aggregate form. They believe, therefore, in *four* aggregate forms of matter,* viz. the *solid*, the *liquid*, the *gaseous*, and the *imponderable* or purely expansible form. An undeniable *relation* to them is expressed in the four elements of Aristotle—*earth*, *water*, *air*, and *fire*, which may respectively represent the solid, liquid, gaseous, and purely expansive form.

Having thus described the general forms and properties of bodies, we shall proceed, in the following chapters, to consider the phenomena to which they give rise, and the laws to which all of them are subjected.

RECAPITULATION.

QUESTIONS FOR REVIEWING THE MOST IMPORTANT PRINCIPLES CONTAINED IN CHAPTER I.

[§ 2.] What is the object of natural philosophy?

[§ 3.] Which of our senses informs us directly of the existence of bodies?

Does the organ of sight always convey a direct proof of the existence of a body? How does sound affect us?

[§ 4.] What properties are common to all bodies? What is magnitude? What do you call the mass of a body? How do you define impenetrability?

* See Tinbor's Philosophy, edited by Dr. August, Berlin, 1829.

[§ 5.] What is the universal term for the infinite variety of bodies, independent of form, magnitude or quality? How do you define *matter?*

Questions on the Divisibility, Porosity, Density, Compressibility, Expansibility, Mobility and Elasticity of Bodies.

[§ 6.] What other properties, besides magnitude and impenetrability, are yet more or less common to all bodies?

[§ 7.] What do you understand by the divisibility of bodies, or matter in general?

Can you prove this geometrically?
Give instances of the extreme divisibility of bodies.

[§ 8.] Is the space which bodies occupy throughout filled with their own substance? What do you call the places which are not filled with a body's own substance? Is this a property belonging to any body exclusively?

Is it necessary to suppose that pores are vacui? How, then, can you account for fluids entering the pores of solid substances?

What do the pores of bodies, or the cellular texture of plants and animals, explain?

[§ 9.] What do you understand by the *density* of bodies? When do you call a body more or less *dense* in comparison with another?

Give an instance.

[§ 10.] What do you understand by the *compressibility* of bodies?

Explain the experiment represented in Fig. 2.

[§ 11.] What property of bodies do you call *expansibility?*

Give an instance.

[§ 12.] What power has every body in animated nature? What is this faculty called? What do you call the universal capacity of bodies of changing their places or relative positions? What is the act itself of proceeding from one place to another called?

Does the capacity for motion belong only to the body, or do its particles, also, participate in it? How is this manifested?

[§ 13.] What do you call that property of bodies which enables them to change their form, when some exterior force is applied to them, but reëstablish it again when that force ceases to operate? Does this property belong exclusively to some bodies?

Give examples of the elasticity of bodies.

Questions on the infinite Variety in the material Composition of Bodies, Atoms, Molecules, and Particles of Matter.

[§ 14.] What bodies do you call *homogeneous?* what *heterogeneous?*

[§ 15.] In what manner do some philosophers account for the infinite variety of substances? What do they call the ultimate particles of matter? On what, according to their opinion, do the taste, shape, texture, color, &c., of bodies depend?

[§ 16.] According to the atomistic theory, what are the smallest particles obtained by the mechanical division of bodies yet composed of?

Questions on Attraction, Adhesion, Cohesion, Terrestrial Gravity, and Gravitation.

[§ 17.] What dispositions do the particles obtained by the mechanical division of bodies evince, when they are brought in contact?

Give examples.

How can you account for these phenomena? What do you call that invisible power which compels bodies and their particles to that mutual approach? When is this power called *cohesive* attraction?

[§ 18.] Is the power of attraction only manifested in the adherence of one body to another?

Where does it exist in a still higher degree?

Give examples.

What is that species of attraction called, which manifests itself by the greater or less resistance offered to the mechanical division of bodies? What is the principal difference between *cohesive* and *adhesive* attraction?

[§ 19.] What other remarkable kind of attraction is evinced by the disposition of all bodies to descend in straight lines to the surface of the earth? Give examples.

What do you call that kind of attraction which is no longer confined to the contact, but impels all free bodies to descend to the earth?

[§ 20.] What do you call the direction in which a falling body approaches the earth? How can you exhibit it? What do you call lines or planes which are at right angles with the direction of gravity? what, those which form oblique angles with the direction of gravity?

[§ 21.] What inference, with respect to gravity, can be drawn from the fact that the earth is a sphere?

Explain Fig. 3. At what distance from each other can you suppose the directions of two plumb lines parallel to each other? Why?

[§ 22.] What do you understand by the absolute weight of bodies?

What difference is there between gravity and weight? In what proportion are the absolute weights of bodies? Give instances.

[§ 23.] In what manner do we determine the absolute weights of bodies?

[§ 24.] What must we know, in order to determine which of two given bodies has the greatest density? What is meant by *specific* gravity of bodies? In what proportion are the specific gravities of bodies?

Give an example. How do you determine the specific gravity of bodies?

[§ 25.] Is the cause of the attraction of gravity situated in any particular part of the earth? What can be proved, in this respect, both by experience and mathematical reasoning? Explain Fig. 4. Explain the experiment of *Cavendish*, represented in Fig. 5. Why do we not oftener perceive the mutual attraction which exists between two bodies placed at certain distances from each other?

[§ 26.] Is the principle of mutual attraction solely confined to the bodies on our globe? What does astronomy teach us? What do you call the attraction between the sun, moon and planets of our system? What important

truth did Sir Isaac Newton discover, in regard to the moon and the planets?

Questions on the Aggregate Forms of Bodies.

[§ 27.] Among the infinite varieties in the form of bodies, which of them strike our senses most palpably? What do all bodies possess which are more easily divided in one direction than another? What are these bodies called? What is their form called?

Give examples.

[§ 28.] What is the second important form of matter? What are those bodies called, whose particles are with the greatest ease separated or removed? What is their form called?

[§ 29.] Do all fluids exhibit the same physical properties? Into how many classes may the fluids be divided? What fluids are designated by the name of *liquids?* what fluids are known by the name of *gases?* What is the form of the latter called?

Give examples of liquids. Give examples of gases. To what class of bodies does steam belong?

[§ 30.] What are the three principal forms of matter, according to which they are either solid, liquid or gaseous, called? Does it follow from this, that a body, exhibiting one of these forms, is, on this account, incapable of assuming another? What does experience teach us in this respect?

Give examples.

[§ 31.] What is that process called, by which solids are liquefied by means of heat? Are there many solids which resist the action of powerful degrees of heat? To what conclusion, therefore, are we naturally led?

[§ 32.] What do you call those fluids which obey the laws of gravity? What fluids are reckoned to those? What do you call those fluids which are either not at all, or at least not sensibly, affected by gravity?

What relation do the four elements of Aristotle bear to the aggregate forms of bodies, if the imponderable fluids are represented by fire?

CHAPTER II.

OF THE PHENOMENA OF COHESION, ADHESION, AND AFFINITY.

§ 33. *Method of determining the Cohesion of Bodies.* If we suspend several cylindrical or prismatical rods, and attach to their lower ends as much weight as is necessary to tear them asunder, we determine thereby the *cohesive powers* of the substances, of which these rods are composed. In the same manner we determine the strength of cords, ropes, &c.

According to Muschenbroek, the power of cohesion in different metals decreases in the following order:—

Iron,	Japan Copper,
Fine Silver,	English Tin,
Swedish Copper,	Zinc,
Fine Gold,	English Lead.

The cohesive powers of wood rank in the following order:—

Oak,	Elm,
Birch,	Pine.

Silk cords are almost three times as strong as flax cords of the same thickness. A thread made of human hair is stronger than one of horse hair of the same thickness. The tarring of cordage diminishes its strength considerably. Bleached thread is weaker than unbleached, &c. The power of cohesion, in metals, is sometimes increased by moderate hammering, rolling, casting, drawing, &c. Some bodies become stronger when exposed to the atmosphere or to heat. This is the case when their pores are filled with liquids which diminish the power of cohesion, and which evaporate when exposed to the air. A composition of different metals is, in many cases, much stronger than either of the component parts. This we see in brass, bronze, &c.*

§ 34. The attraction of cohesion manifests its whole

* See Tobias Mayer's Elements of Nat. Phil.; also, Buffon's Expériences sur la Force des Bois; also, Petr. v. Muschenbroek's Introd. ad Cohærentiam Corporum Firmorum.

strength only in *absolute contact*, when the particles of a body have the situation given them by nature: when a particle of matter is once separated, this perfect contact cannot be reëstablished by putting it again in its place; but it will, nevertheless, *adhere* to the body with considerable force.

We are now able to explain the strong adherence between two well-polished plates of glass, marble, or metal, to which we have alluded in § 17, Chap. I. By the act of polishing, all protuberances and cavities of the two flat surfaces, which would necessarily prevent their intimate contact, are removed, and they are consequently permitted to touch each other in more points But the more points of contact they present, the stronger must, necessarily, be their adhesion; the greater, therefore, must be the power required for their separation. If, in the above experiment, any liquid (even water) be brought between the two contiguous surfaces, then the contact, and, consequently, also, the adhesion between them, is considerably increased. If, moreover, this liquid be one which, by cooling or drying, becomes hard, then the adhesion can be carried to a degree which even surpasses the cohesive attraction between the two contiguous bodies. Instances of this kind are daily exhibited in the mechanic arts. The processes of brick-laying, gluing, luting and soldering of metals, together with a variety of other technical performances, are explained on this principle. Instances of simple attraction, produced merely by *intimate contact*, are the gilding, silvering or plating of metals, the silvering of looking-glasses, &c.

§ 35. The phenomena of adhesive attraction are not only exhibited between particles of the same body, but are equally manifest, also, in the contact of heterogeneous substances. Hence the attraction of adhesion is a power as universal as that of cohesion.

EXPERIMENT. Take some fine sand or dust, which strew on any of the flat faces of a solid body; then turn the body gently, so that the dusty surface may face the ground; only the heavier grains of dust or sand will fall off; the others will be retained by the adhesive attraction of the body, contrary to the laws of gravity; for it must be observed, that, in this experiment, the adhesive attraction becomes manifest only when it overcomes the attraction of gravity. If, instead of sand or dust, some other powdered substance be used, similar effects will be produced, and it will be found that the *nature* of the body used for the experiment has but little influence upon the result.

§ 36. *Influence of Cohesion on the Aggregate Forms of Bodies.* The most striking effects produced by the different modification of cohesive attraction are, evidently, the three aggregate forms of bodies. That these are actually the

result of such modifications, will be best understood by the following considerations:—

It can be mathematically proved, that the agency of cohesion in a fluid, let its mass be great or small, is such that it must assume a spherical form, when it is not prevented from doing so by other powers operating upon it at the same time.* This explains the formation of drops, the convex surface of aqueous liquids, in greased vessels, the round shape of the heavenly bodies, and corroborates, at the same time, the opinion that all bodies have once been in a liquid state. (See § 31, page 28.)

§ 37. From this state of perfect liquidity, matter becomes gradually solid, and partakes of a certain texture by the attraction of cohesion acting more strongly in one direction than in another. This is the reason why all solids are more easily divided following certain directions; for, if the cohesive attraction were the same in every direction, the effects would mutually destroy and cancel each other, and a body might be perfectly dense, and, at the same time, perfectly liquid. Hence, we may conclude, first, that the reason why the particles of a fluid change so easily their relative position, is because *they attract each other equally in all directions;* and, secondly, that *the solidity of bodies originates in their particles not being equally attracted in all directions.*

Thus an animalcule moves about with the greatest ease in a drop of water, because it has not to *overcome* the cohesion of the liquid, but merely to change the relative position of its particles. It is a different case when a drop is actually to be *separated* from the rest; because then the *cohesion* of the liquid will offer considerable resistance. Hence, an animalcule, though moving with great facility in a drop of water, finds it difficult to rise above the surface. Aquatic insects, needles, or small pieces of sheet iron, although heavier than water, do not sink until they are immersed; that is, until the cohesion of the liquid is overcome by the separation of its particles. Between the liquid form and the state of perfect solidity, there are infinite transitions, of which language can only designate the most prominent. Thus

* A sphere is a body, every point of whose surface is at an equal distance from one and the same point, called the *centre*. Now, as the attraction of cohesion acts from any one point equally, in *all directions*, it is easily perceived that the particles of matter will be obliged to arrange themselves at equal distances from that point, which will therefore be the centre of a sphere, of which the most extreme particles will compose the surface.

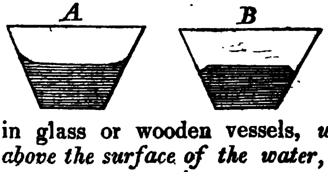
we call a body *hard*, when it is difficult to divide or change the position of its particles; and *soft*, when it possesses opposite qualities. When a body is easily bent, but not broken, it is called *ductile;* and when it is easily broken, without bending, it is called *brittle*. When a body yields easily to the hammer or the rolling press, it is called *malleable;* and so on.

§ 38. For the form of elastic fluids, we cannot account in any other way than by supposing that the cohesive attraction between their particles is so small, that they are prevented from forming any regular arrangement; or, what is still more plausible, that their particles are, by some imponderable fluid (probably caloric), kept at too great a distance from each other to allow the cohesive attraction to operate.

This opinion seems to be corroborated by the fact, that many gases can, by mechanical pressure, be reduced to the liquid state; because, by pressure, their particles are brought into more immediate contact.

§ 39. *Shape of Liquids in Vessels.* On account of the spherical form which every fluid matter necessarily assumes when solely acted upon by the attraction of cohesion among its particles, every liquid enclosed in a vessel ought to exhibit a convex surface; but as the particles of the liquid are at the same time solicited by the general attraction of gravity, the surface becomes flattened and almost horizontal. If, in addition to this, the liquid is strongly attracted by the sides of the vessel, above the surface, then it will rise around those sides, and its surface will become *concave.* This does actually take place with water poured into glass or metallic vessels; whereas quicksilver, in vessels of glass or wood, exhibits a convex surface, because the particles of quicksilver attract each other more strongly than they adhere to glass or wood, and are therefore more at liberty to follow the attraction of cohesion. A (Fig. 6) represents the surface of water, and B, that of quicksilver, in a glass vessel. A convex surface is also exhibited by water in glass or wooden vessels, *when the sides of the vessel, above the surface of the water,* are greased with fat or oil.

Fig. 6.

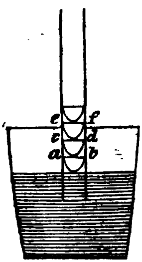


This seems to prove that the surface of liquids depends entirely upon the sides of the vessel, and particularly upon that portion which remains *above* the liquid; so that, *if the cohesion of the liquid is less than its attraction to the sides of the vessel, the surface will be concave; while, on the contrary, it will exhibit a convex surface when its cohesion is greater than the attraction to the sides of the vessel.* When a vessel is entirely filled with water, so that no portion of its sides remains above the surface, there being no room for the liquid being attracted by the sides of the vessel, and consequently no possibility of its assuming a concave surface, we can always add a small quantity without making it overflow, and the water, being now solely solicited by the power of cohesion, exhibits again a convex surface.

What has just been said about the surface of liquids, will serve to explain a number of phenomena, some of which it will be easy for the teacher to show to his pupils. Little balls of cork-wood, for instance, when thrown into a wooden or glass basin, which is filled with water, are attracted by its sides; and when these are greased, and covered with witch-meal, they are repulsed by them.

§ 40. *Phenomena of Capillary Attraction.* When a narrow glass tube, which is open at both ends, is immersed in water, or in any other liquid which strongly adheres to glass, the liquid in the tube will rise above the surface in the vessel.

Fig. 7.



The liquid in the tube will, according to what has been said, form a concave surface; that is, it will rise higher along the sides of the tube than at its centre. (See the figure.) Now, if the tube is very narrow (a capillary tube), then the particles of the liquid which rise along the sides are sufficiently near each other for their cohesive powers to act. Accordingly, they flow in one, and form a little column, *abcd*, above the surface of the liquid in the vessel. But as soon as this is completed, the liquid rises again along the sides of the tube, and, by a new confluence, forms a new column, *cdef;* and this process continues until the weight of the column thus formed is in equilibrium with the attraction of the liquid to the sides of the tube. An ingenious application of this kind of attraction is made in the *capillary siphon,*

which consists of a hank of cotton thread, one end of which is dipped into a vessel which easily adheres to cotton, and the other end is conducted to the vessel to which the liquid is to be transferred. A bent glass tube, of a very small bore, will answer the same purpose.

§ 41. The attraction of a liquid to the sides of a narrow tube which is immersed in that liquid, is called *capillary attraction*. The same phenomenon, however, may be produced *by bringing the tube merely in contact with the surface of the liquid.*

EXPERIMENT. If, directly over a drop of water, you place the open end of a capillary tube, it will not only enter and rise in the tube, but, if its weight is less than that of a column of water, which, by the capillary attraction of the sides, may be raised in the tube when *immersed* in water, the whole drop will, as if by suction, be absorbed by the tube, and continue to remain in it, even when the tube is moved from its position, contrary to the laws of gravity.

§ 42. *In order that a liquid shall rise in a capillary tube, the tube must be made of a substance which attracts the particles of the liquids stronger than they attract each other.* This is the reason why quicksilver does not rise in a glass tube, or water in a tube whose sides are greased with fat. But quicksilver rises in a capillary tube made of tin or lead, or in glass tubes which have been lined with fat or oil.

What has been said about capillary attraction is sufficient to explain why water and other liquids enter the interstices of solid substances, such as wood, sugar, lime, paper, &c. Moreover, it may be proved that the phenomena of capillary attraction are independent of the pressure of the atmosphere, as they take place, also, under the receiver of an air-pump, an instrument which will be described hereafter, when treating of the atmosphere.*

§ 43. *Solution of Solid Substances.* When liquids enter the pores of solid substances, it often happens that the cohesion of the particles of the solid is overcome; they consequently lose their texture, and unite so perfectly with the liquid as to make with it but one homogeneous mass.

* All natural philosophers do not agree in their mode of explaining the various phenomena of capillary attraction. The most complete and mathematical theory of it is given by La Place, in the supplement to his Mécanique Céleste. It has since appeared separately as a pamphlet—Théorie de l'Action capillaire, par M. La Place. Paris, 1807.

In this case we say, the solid has been *dissolved*. The result of the whole operation is termed a *solution*, and the liquid in which this takes place, its *medium*.

EXAMPLES. Sugar, common table salt, saltpetre, and a variety of other bodies, are totally dissolved in water. Hence we speak of a solution of sugar, of salt, of saltpetre, &c., of which *water* is the medium. In the same manner is silver dissolved in nitric acid, gold and platinum in nitro-muriatic acid, &c. In these instances, nitric and nitro-muriatic acid, respectively, are the mediums of the solution; and in all these cases, the union or combination between the solid and the liquid is so perfect, that, even with the best microscope, no particles of the solid are perceptible in the solution.

§ 44. *Chemical Affinity.* Such a solution evidently requires a strong mutual attraction between the solid and the liquid; and *this mutual attraction, through which two heterogeneous substances combine with, or dissolve each other, is called affinity.* This is the fourth species of attraction with which we have become acquainted. It operates only in *contact*, and its *effects are always accompanied by a material change in the exterior properties of bodies;* wherefore *affinity* has also been defined to be *that peculiar kind of attraction which is only manifest in contact, and which is the cause of a change in the properties of bodies.*

Some substances combine more easily with each other than with other substances: some cannot be dissolved at all, and others only after certain preparations, such as heating, pounding, powdering, &c. The degrees of affinity, therefore, vary in different substances; but experience and observation alone can teach us which substances have greater affinity for one another than others.

§ 45. *Point of Saturation.* Most liquids combine only with a definite quantity of a given solid substance, after which all affinity ceases between them and that part of the solid which remains undissolved. The liquid is then said to be *saturated* with the solid, and the point beyond which the chemical attraction ceases to operate is called the *point of saturation.*

EXAMPLE. If several large lumps of sugar or salt are thrown into a tumbler of water, the attraction between them and the water will only operate to a certain point, after which a considerable quantity of the sugar or salt will remain undissolved at the bottom of the vessel. If a quantity of pure water be now added,

it will dissolve a fresh portion of the sugar or salt, and, by increasing, from time to time, the quantity of water, we may finally obtain a complete solution of the solids. We may infer from this and similar experiments, *that the quantity which a liquid can dissolve of a given solid is in proportion to the volume of the liquid.* Besides this, the temperature of the liquid which is to be dissolved, together with the degree of affinity which exists between them, has a great influence upon the degree of saturation. But heat does not always favor the dissolution of bodies; thus, although hot water will dissolve more sugar than cold water, it does not dissolve more common salt than water near the freezing point. Boiling water dissolves even less magnesia than water at the common temperature of the atmosphere.

§ 46. *Engagement—Decomposition.* The more a solution is saturated, the less are we able to distinguish the properties of its component parts. The two substances which have thus combined to form a new body, are then said to be *engaged* in it; and when, by some process or other, one of the component substances is again separated from the solution, and made to assume its former state, we say, *it has become free;* and the solution is *decomposed.*

Thus salt and water are said to be engaged in a solution of the former in the latter: gold is engaged in a solution of nitro-muriatic acid; silver in a solution of this metal in nitric acid, &c. But when a solution of common salt is, for some time, exposed to a gentle heat, all the water will evaporate, and the salt will remain in a solid state. In a similar manner is candied sugar obtained from a solution of sugar in water. Gold is revived from a solution in nitro-muriatic acid, by throwing into it a substance called *proto-phosphate of iron,* or the acid termed *phosphoric acid.* In all these cases, the solutions have been *decomposed,* and the salt, sugar, or gold, have been *disengaged,* or *set free.*

§ 47. *Chemical and Mechanical Division—Chemical Compounds and Ingredients.* We have now become acquainted with another kind of division of bodies, different from that mentioned in § 7, page 15. We have learned that a homogeneous substance, in which, by the best microscope, no dissimilar particles are perceptible, may yet, by the influence of heat, or by the addition of a third body, be divided into parts possessing apparently heterogeneous properties. This is called a *chemical division* or *separation.* The parts obtained by it are said to be the *ingredients* or *compo-*

nent parts of the body; and the body itself is said to be a *compound* of these ingredients.

In the example given in the preceding section, the solution of salt is a compound of salt and water, and the salt and water are the ingredients of the solution. Gold and nitro-muriatic acid are the ingredients of the solution of gold, and the solution itself is composed of these ingredients.

The mechanical division, alluded to in § 7, consists in separating the particles of a body, by the application of some external force, without changing the nature or properties of the body. To this kind of division belong the cutting, grinding, and pounding of solids, wire-drawing, pouring out of liquids, &c. The parts or particles thence obtained have apparently yet the same properties which they had before the separation; and for this reason they are called the *integral* parts, because they differ from each other, and the body from which they are obtained, merely in *magnitude*, and not in substance.

§ 48. *Nearer and Remote Ingredients of Bodies.* When a body has been chemically separated into two or more ingredients, it frequently happens that these ingredients are themselves compounds, which, in their turn, are again capable of decomposition. In this case, the component parts of the first division are called the *immediate* or *nearer ingredients*, and those which are obtained by the further decomposition of these, are called the *more remote ingredients*, of the body.

Example. Saltpetre is a compound of nitric acid and potash; but nitric acid may again be decomposed into two substances, called nitrogen and oxygen, and potash is a compound of a metal called potassium and oxygen. Hence nitric acid and potash are the nearer, and oxygen, nitrogen and potassium the more remote, ingredients of saltpetre. Again, the well-known salt of Glauber may be decomposed into sulphuric acid and soda; but the former may again be decomposed into sulphur and oxygen, and the latter into a metal called sodium and oxygen; hence sulphuric acid and soda are the nearer, and oxygen, sodium and sulphur the more remote, ingredients of Glauber's salt.

§ 49. *Elements.* When the chemical division of a body has been carried so far that the last ingredients can no longer be decomposed, we say that we have arrived at the *ultimate principles* of which the body was compounded; and

the substances which we are no longer capable of decomposing are termed ELEMENTS.

We must not infer from this, that a body, which is termed an element, is, by *its nature*, incapable of further decomposition; the term "element" is only indicative of the state of our knowledge with regard to those substances, and *our* inability to decompose them; but they may for all this be compounded of two or more ingredients, which, at this stage of the science, we are unable to detect. Thus water was considered an element till about sixty years ago, when it was decomposed into two gases, hydrogen and oxygen, which are therefore the ingredients of water. Atmospheric air was for a long time considered as an element, until the discovery of nitrogen and oxygen proved that it is principally composed of these two substances. The alkalies, potash, soda, &c., were, until of late, considered as elements; but each of them is now proved to be a combination of a distinct metal with oxygen, and the same is the case with the earths. These examples will suffice to show the extreme caution with which it is necessary to proceed in the natural sciences, and the care which we must take not to confound our *opinions* of things with the *facts* on which those opinions are founded.

§ 50. *Crystallization.* When a body passes slowly from the liquid to the solid state, that is, when, from a state of solution, it becomes gradually converted into a solid, then, in most cases, its particles arrange themselves with great regularity and symmetry, exhibiting generally complete mathematical figures. These figures are called *crystals*, and the process itself is termed that of *crystallization.*

EXAMPLES. We have already observed (§ 46.) that by slowly evaporating a solution of common salt, the salt will be reproduced in a solid state. If the little particles thus obtained are now carefully examined, they will be found to form regular four-sided pyramids or cubes: these, therefore, are the crystals of common salt. If a solution of Epsom salt be treated in the same manner, colorless four-sided prisms are obtained, which are therefore the crystals of Epsom salt. In a similar manner may saltpetre be crystallized into regular six-sided prisms, sulphate of lime into right or oblique prisms, &c.

The crystallization of bodies is the manifest result of the undisturbed action of the attraction of cohesion; because, when the solution is shaken, or when the temperature is suddenly in-

creased or diminished, no such symmetrical forms are produced: an irregular mass, or misshapen irregular bodies, are the result of the operation. For the peculiar properties of crystals, and the different theories respecting them, see Chemistry, Chap. IV. on Crystallography.

The theory of chemical combinations and decompositions was, some years ago, considered as a part of natural philosophy; but it has since become so complicated and extensive, that it was necessary to treat of it separately, under the head of *Chemistry*, as a distinct branch of the natural sciences.

We shall proceed, therefore, to consider the *laws of motion*, or the *mechanical properties* of matter, and refer the learner for the above theory to our treatise on Chemistry.

RECAPITULATION.

QUESTIONS FOR REVIEWING THE MOST IMPORTANT PRINCIPLES CONTAINED IN CHAPTER II.

[§ 33.] By what methods are the cohesive powers of solid substances determined? How is the cohesive power of ropes determined?

Can you tell me the order in which the power of cohesion decreases in the principal metals? Can you tell the same order with regard to wood? Which of two cords of equal thickness is stronger, one made of silk, or one made of flax? Does the tarring of cordage increase or diminish its strength? Is bleached thread as strong as unbleached thread? What means have we to increase the power of cohesion in metals? In what cases do bodies become stronger, when exposed to the atmosphere, or to heat?

[§ 34.] When does the attraction of cohesion manifest its whole strength only? What takes place when the particles of a body once separated are again brought in contact with each other?

What phenomena does this explain? How are the processes of bricklaying, gluing, luting, soldering, explained?

[§ 35.] Are the phenomena of cohesive attraction only exhibited between particles of the same substance? What conclusion do we draw from this?

Explain the experiment described in § 35.

[§ 36.] What are the most striking effects produced by the different modifications of cohesive attraction?

What is the form which every mass would assume if solely obeying the law of cohesion of its particles? What does this explain?

[§ 37.] What is the reason that bodies, from a state of fluidity, become gradually solid, and partake of a certain texture? What would be the case if the cohesive attraction were the same in all directions? What inferences may be drawn from this?

Why does an animalcule find it difficult to rise above the surface of water? Why do aquatic insects, needles, or small pieces of sheet-iron, not sink until they are immersed?

When do you call a body *hard*? When *soft*? When *ductile*? When *brittle*?

[§ 38.] How can we account for the form of elastic fluids?

By what facts is this opinion corroborated?

[§ 39.] What form ought every liquid, enclosed in a vessel, exhibit, on account of the spherical form which it has when solely acted upon by the cohesive attraction of its particles? But what takes place in consequence of the attraction of gravity? What, if, in addition to this, the liquid is strongly attracted by the sides of the vessel?

Give instances of both. When does water exhibit a convex surface in glass or wooden vessels? What does this seem to prove? Why can we always add a small quantity of a liquid to a vessel which is already filled with that liquid, without making it overflow?

What other phenomena are explained on the same principle?

[§ 40.] *What takes place when a narrow glass tube, which is open at both ends, is immersed in water, or in any other liquid which strongly adheres to glass?*

Explain Fig. 7.

What ingenious application has been made of this kind of attraction?

[§ 41.] What do you call the attraction of a liquid to the sides of a narrow tube, which is immersed in that liquid? Is the actual *immersion* of the tube in the liquid necessary to produce the phenomena of capillary attrac-

tion? By what other means may the same phenomena be produced?

Describe the experiment—§ 41.

[§ 42.] *What are the conditions in order that a liquid may rise in a capillary tube?* What does this explain?

Are the phenomena of capillary attraction dependent on the pressure of the atmosphere? How has this been proved?

[§ 43.] What does often happen when liquids enter the pores of solid substances? When is a solid body said to be dissolved? What do you call the result of the whole operation? What the liquid itself?

Give examples.

[§ 44.] *What do you call that mutual attraction by which two heterogeneous bodies combine with, or dissolve each other?* By what are the effects of chemical attraction or affinity always accompanied? How, therefore, may you *define* affinity?

Is the degree of affinity for other substances the same in all bodies?

[§ 45.] When is a liquid said to be *saturated* with a solid? What do you call the *point of saturation?*

Give examples.

What may we infer from this? Does heat *always* favor the solution of solids? Give instances where it does not.

[§ 46.] What are the two substances said to be, which combine mutually to form a new body? And what do we call the body, which, by some process or other, becomes again separated from the solution? What is the solution itself, in this case, said to be?

Give examples.

[§ 47.] Can you now explain what you understand by the chemical division or separation of bodies? What are the parts obtained by this division called? What is the body itself called?

What are salt and water the ingredients of? What gold and nitro-muriatic acid?

In what does the mechanical division of bodies consist? Give instances of this kind of division. What properties do

the smallest particles obtained by this kind of division yet possess? What are they, for this reason, called? In what respect only do they differ from the body from which they are derived?

[§ 48.] What do you understand by the *nearer* or *immediate* ingredients of a body? What, by the *more remote* ingredients of a body?

Give an example.

[§ 49.] When do we say we have arrived at the *ultimate* principles of which a body is composed? *What are those substances which are no longer capable of further decomposition called?*

Does it follow that, because a body is *called* an element, it is actually incapable of further decomposition? What, then, does the word *element* indicate?

Give examples of bodies which were formerly taken for elements, but are now proved to be compounded of other principles.

[§ 50.] In what manner do the particles of most solids arrange themselves, when slowly passing from a state of solution to that of a firm substance? What are the regular figures thus formed called? What is the process itself called?

Give examples of the crystallization of bodies. What is the crystallization of bodies the manifest result of? Why?

CHAPTER III.

THEORY OF EQUILIBRIUM AND MOTION OF BODIES.

§ 51. *Absolute Place, Situation, Motion of Bodies.* Every body exists somewhere in space. This is called its *absolute place* or *position*. By comparing it with the place of other bodies, we are led to the idea of *situation* or *relative position*. A successive change in the position of a body or its particles is called *motion*.

Absolute motion cannot be perceived through the medium of our senses: we merely conclude that a motion has taken place, when a body has changed its position with regard to others.

EXAMPLES. In determining the place of a city or port on our globe, we find how many degrees it is removed from the equator, and how many degrees east or west of the meridian of Greenwich; that is, we determine the *latitude* and *longitude* of the place, which is referring it to the distance from two fixed lines, the equator and the meridian passing through Greenwich. In determining the position of a minor place, we refer it to a certain distance south, north, east, or west of a city. The place of a house is referred to a street; the place of a room in a house by its relative position in the first, second, or third floor, occupying the east, south, north, or west corner of the house. An object in the room is referred to its distance from the walls or ceiling, &c. But we know nothing of the absolute position of the earth itself; for although we may trace it to its distance from the sun, yet the position of the sun himself, with regard to the fixed stars, is not known.

That *absolute* motion does not come within the reach of our senses, is evident from a great number of facts. Thus a person sitting in the cabin of a vessel does not perceive the rapidity of his motion, because he shares it in common with all the objects around him; but when on deck, he may, from the apparent motion of the water, judge of the swiftness with which the vessel is sailing. The immense velocity of the diurnal rotation of the earth, or its revolution round the sun, is not perceived, because all things around us share in it, and it would have

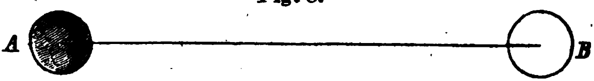
remained forever a secret to us, had we not been able to judge of it by the changes in the relative position of the planets and the stars.

§ 52. *The State of a Body in which it continues without Motion or Change of Position, is termed the State of* QUIESCENCE, *or of* REST. This, as we shall presently see (§ 58), is the state in which every body perseveres, until, by some cause or other, it is compelled to change it for that of motion.

§ 53. *Way, Orbit.* When a body is in motion, we consider it abstractedly as a mere point, which approaches others, or removes from them. Hence we say, *the body describes a line*, which is its *way* or *orbit*. This may be a straight or a curve line, according as the moving body continues in the same direction or changes it continually.

Thus, when the body A (Fig 8.) moves from A to B, we say it describes the line AB.

Fig. 8.



§ 54. *Time.* Every kind of motion requires time; because a body cannot, at once, be in two points of its orbit. We measure time by years, months, weeks, days, hours, minutes, &c.

§ 55. *Velocity.* When we compare the time which a body needs to move from one place to another, with the distance which is between them, we form the idea of *velocity*, which is estimated by *the space which a body goes through in a certain time* (a minute, a second, &c.). Of two bodies which are in motion, that is said to have the greater velocity, which, in the same time, passes through a greater space.

EXAMPLE. If two bodies, A and B, have both been moving during the time of 5 minutes, and A has gone through the space of 100 feet, but B only through 50 feet, then the velocity of the body A was $\frac{100}{5}=20$ feet per minute; whereas that of the body B was only $\frac{50}{5}=10$ feet. Hence A has moved with double the velocity of B.

§ 56. *Uniform, Accelerated and Retarded Motion.* When we consider the velocities of bodies, we call their motion *uniform*, *accelerated* or *retarded*, according as the spaces

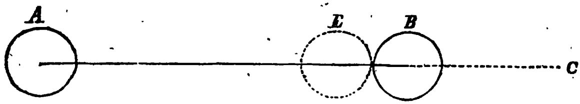
gone through, in equal times, are equal, or become successively greater or smaller.

Thus the motion of a body, A, which has passed through the space of 50 feet in 5 minutes, is said to have been *uniform* when it has described 10 feet in each minute. But it would have been *accelerated*, if it had passed through 4, 6, 8, 12, and 20 feet, during the first, second, third, fourth, fifth, minutes respectively. If, on the contrary, it had moved through the space of 20 feet in the first minute, 12 feet in the second, 8 in the third, 6 in the fourth, and 4 in the fifth minute, its motion would have been a *retarded* one.

§ 57. *Action and Reaction of Bodies.* When a body, A, is in motion, it has the power of moving another body, B, which is in its way, or at least to change its motion. When this takes place, we say the body A has *imparted motion* to the body B. While it is thus acting upon B, a part of its own force or motion is destroyed. This is called the *reaction* of the body B upon A. Now, as the force of the body A can be diminished only as far as it finds resistance in B, it follows that *action and reaction are equal to one another;* that is, A loses as much of its own force, as it imparts to B.

For an illustration, let us consider the following experiment:—

Fig. 9.



Let A and B be two heavy, equal masses, which we will suppose to be perfectly unelastic. Let B be quiescent, and A moving from A to C with a velocity 10. After the impact in E, the two bodies A and B will both continue their way towards C with the velocity 5. B will have received 5, and A have lost 5; consequently, the action of A upon B was equal to the reaction of B upon A, A having lost as much as B gained.

§ 58. *Every motion, as well as every change of it, in velocity or direction, must proceed from a cause or power, which, by soliciting the body, produces this effect.*

Without such a cause, every body in nature would remain in the state of rest or motion once assumed. This universal principle is termed VIS INERTIÆ.

The first part of our proposition implies nothing else than that no body can, from a state of rest or quiescence, voluntarily change its place or position. This is indeed self-evident, and the result of the most universal human observation. A body capable of changing its position by virtue of its own *will*, is an animal, endowed with a vital principle, which is altogether undefinable, and, in all probability, distinct from matter. Neither is the locomotive power of an animal seated in any particular muscle or limb: it belongs to it as a whole, and perishes with it by its death. But the more special object of the natural philosopher is, the investigation of the properties of lifeless or *inanimate* matter, or those qualities which belong to bodies independent of any power which gives them life, or a peculiar *organization*. Here, the most universal phenomenon which presents itself to our eyes is, that no *thing* can change its position without a *cause*. Place a book on a table, and let it remain untouched; you will find it there after years, and if the house itself is not removed, no one can doubt but that it will remain there forever. No period can be put to the continuance of an inanimate body, at the place where it once is, or the position it has once assumed. Not the smallest particle of matter, not an atom, is removed from its place without a sufficient cause. But perhaps it is not quite so easy to understand the second part of our proposition,—that *every body once in motion continues in it until some other cause or power sets it at rest.* For this purpose, let us, for a moment, consider whether a body which is once in motion, stops *of its own accord*, or whether the gradual decay of motion to which every body is subjected, is the result of some *impediment*, which it finds on its way; and which, by *acting upon the body, arrests its velocity, or renders it quiescent.* When a stone is rolled upon the ground, the roughness and irregularities of its surface, as well as those of the ground, will soon arrest its motion. Change the stone for a ball, and it will roll much longer. Substitute, now, a steel ball highly polished, and move it along a well-polished steel surface, and the smallest motion communicated to the ball will last for a very considerable time.

It is obvious, that, in these successive experiments, the impediments opposed to the motion of the body consisted

in the unevenness of the surface; for in proportion as this was removed, the motion continued longer. But this obstacle to motion, which is termed *friction,* is not the only obstruction to it. There is yet another cause for the discontinuation of all motion on the surface of our globe: this is *the resistance of the atmosphere.* Of this, daily observations and repeated experiments furnish sufficient proofs. If an umbrella be carried, on a calm day, with its outside against the direction you are moving, you will experience a resistance to your motion which will increase in proportion as you are increasing your speed. The same impediment will be offered to an animated body, moving in any direction you please; and the subsequent diminution in motion will be proportionate to the velocity of the body, and the surface presented to the air. A top will spin several hours in very rarefied air; a pendulum will swing a whole day under the receiver of an air-pump from which the air has been exhausted; and if the same pendulum moves on a diamond point, so that the friction is very small, it will swing uninterruptedly for many days. Now, all these facts would serve to establish the doctrine of *inertia,* if it were not evident from the force of reasoning alone. For, to suppose that a body can diminish its velocity by a single inch per second, is the same as supposing that it has an innate power to reduce, *in the outset,* the velocity of an inch to the state of quiescence, which is just as absurd as the supposition that from a state of perfect rest it can give itself the velocity of an inch.

Other Experiments and Facts, proving the Correctness of the Theory of Inertia. When a loaded wagon, which is in motion, is to be stopped, the horses have to exercise the same power which is necessary to *back* the vehicle if it were at rest. If a person is running down a hill, he cannot voluntarily stop at the foot of the elevation, but is obliged, from his body having once acquired a certain velocity, to run a considerable distance before he can render his body quiescent. If a passenger leaps from a carriage which is rapidly drawn, he will fall to the ground in the direction in which the carriage moves; because his body, retaining the motion imparted to it by the carriage, is still impelled in that direction, whilst his feet are retained on the ground. When a heavy wagon is to be set in motion, the horses find it difficult to start; but when the vehicle is once in motion, nothing but the friction of the wheels on the ground is to be overcome, and the horses are seen to draw the load with apparent ease, and without much

muscular exertion. A greyhound, pursuing a hare, although moving with much greater swiftness than the hare, finds it difficult to overtake her; because the hare frequently changes her course, when the greyhound, having acquired a rapid motion in the former direction of her course, is irresistibly impelled to continue in it for several yards, until he is able to check his speed, and begin the pursuit on her new course.

§ 59. Whatever produces, or tends to produce, a change in the state of a body, or its particles, with regard to motion, is called a *force*. When a body is acted upon by a moving force, we say the body has received an *impulse*, which will always give it a tendency to move in a straight line. Thus, in the example (§ 57), the body A must have received an impulse in the direction A B.

The principal moving forces in nature are,

1. The universal attraction of gravitation. (Chapter I. § 26.)
2. The attraction of gravity. (Chapter I. § 19.)
3. Chemical attraction, or affinity. (§ 44.)
4. The sinews and muscles of men and animals.
5. The elasticity of steam and gases.
6. Magnetic and electric attraction.

§ 60. *Time required for imparting Motion.* The imparting of motion requires time. This may be shown by a variety of experiments.

One of the simplest is to place a heavy substance, say a piece of copper, on a smooth horizontal surface, which covers a vessel of sufficient diameter. When the cover is suddenly removed, without changing its horizontal direction, the copper will fall into the vessel; which could not be if the motion communicated to the cover were, at the same time, transmitted to the copper

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LAWS OF MOTION.

§ 61. *Uniform Motion.* It has been stated before, that a body is said to be in uniform motion, when it passes through equal spaces in equal intervals of time. *From this definition it follows, that the spaces described by two bodies in uniform motion, are in proportion to their velocities, when the times are the same, and in proportion to the times,*

when their velocities are equal. Thus, of two bodies in uniform motion during the same number of minutes or seconds, that which has the greatest velocity will pass over the greatest quantity of space; and if the velocities are equal, that will describe the greatest space, which moves during the greatest number of minutes.

Suppose two bodies, A and B, have been in uniform motion, A 5, and B 10 seconds. A has gone through 100 feet, B through 50. Then A's velocity is $\frac{100}{5} = 20$ feet per second, and B's $\frac{50}{10} = 5$ feet per second. Hence A's velocity is to that of B as 20 to 5, or as 4 to 1.

§ 62. *The space described by a body in uniform motion, may be found by multiplying the number of minutes, seconds, &c., it has been in motion, by its velocity, expressed in the number of miles, rods, feet, &c., it passes over in a unit of time.*

To give an example: If a body has been in uniform motion during 15 seconds, with a velocity of three rods per second, none will doubt, that the space over which it passed is equal to three times 15, or 45 rods.

§ 63. From the principle established in the preceding paragraph, we may immediately draw the following two inferences:—

1. *The spaces described by two bodies in uniform motion are in proportion to the product of the times, multiplied by the velocities;* for these products give the spaces over which they passed. Then, if two bodies, A and B, have been in motion, A during 10 seconds, at the rate of 6 rods per second, and B during 5 seconds, at the rate of 4 feet per second, the spaces described by these bodies will be in proportion as 60 to 20, or as 3 to 1; because 60 and 20, respectively, are the products obtained by multiplying the times of their motion by their velocities.

2. *The velocities of two bodies in uniform motion are in proportion to the spaces divided by the times.*

Thus the body B, in our last example, which has passed, in uniform motion, over a space of 20 rods in 5 seconds, has evidently had the velocity of 4 rods in 1 second, which is the quotient of 20 divided by 5; whilst A, which has passed over 60 rods in 10 seconds, has moved with the velocity of 6 rods in a second, which is the quotient of 60

by 10: consequently the velocities of these two bodies are as 5 to 6, or, which is the same, as $\frac{20}{4}$ is to $\frac{60}{10}$.*

§ 64. *Momentum of Bodies.—Every body in motion has the power of communicating motion to another body* (§ 57). The degree of that power must necessarily depend upon its mass and velocity. Of two bodies which move with the same velocity, the greatest power will be exercised by the one which has the greatest mass or bulk of matter; and if their masses are the same, the greatest effect must be produced by that whose velocity is the greatest.

§ 65. From this principle we infer, that *the power of a body in motion is measured by the product of its mass into its velocity.* This product is generally called the *momentum* of the body. For an illustration of this principle, let us compare the power of a cannon ball weighing 24 lbs., and whose velocity is 96 feet per second, with that of an 18 pounder whose velocity is 120 feet per second. The momentum of the former is 96 multiplied by 24 = 2304, while that of the latter is 120 by 18 = 2160; consequently the effects produced by these balls are in the ratio of 2304 to 2160, or, which is the same, as 16 to 15.

We see from this that a small body, by virtue of its *velocity*, may have as great a momentum, and consequently produce as great an effect, as a heavy body, with a comparatively small velocity. Thus a body weighing but one ounce, with a velocity equal to 17920 feet per minute, would produce five times the effect of 1 cwt. with only the velocity of two feet per minute. The *momentum* of the former would be 1 multiplied by 17920, and that of the latter 1792 multiplied by 2 (because 1 cwt. equals 1792 ounces). Hence the effects produced by them on any body they meet on their way, would be as 17920 to 3584, or, which is the same, as 5 to 1 (17920 being equal to five times 3584).

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* If S, V, T, respectively, denote the space, velocity, and time of one body, and s, v, t, respectively, denote the space, velocity, and time of another; then we have the proportion

$$S : s = T \times V : t \times v;$$

and, dividing the first and third terms of this proportion by T, and the second and fourth by t, we obtain easily

$$V : v = \frac{S}{T} : \frac{s}{t};$$

which are the mathematical expressions for the above principles. (See Grund's Plane Geometry, Theory of Proportions.)

This example shows the surprising influence of velocity upon the momentum of a body. A still more striking instance of that influence is the fact, that it is possible, with a tallow candle, to shoot through a board of considerable thickness.

§ 66. From what has been said, we may likewise infer, that *the power which is requisite to impart to a body a certain velocity, must be in proportion to the momentum, that is, to the product of the mass of the body, by the required velocity.* Thus a power equal to 2000 lbs. is required to impart to a mass of 100 lbs. the velocity 20; because 100 times 20 = 2000; or, in other words, the power which would impart to a mass of 1 lb. the velocity 2000, will impart to a mass of 100 lbs. only the velocity 20.

A much greater quantity of powder is necessary to impart to a cannon ball the velocity of a common musket or rifle ball. A much greater velocity must be given to a soft substance, to cause it to enter into a solid body (as, in our above example, the tallow candle into a piece of board), than is necessary to impart to a piece of iron or steel, to produce the same effect. To an ounce the velocity 1792 must be imparted to give it the same momentum which the velocity would give to 1 cwt.; because 1 cwt. equals 1792 ounces. On the contrary, a very small velocity may produce an enormous momentum in a large, heavy mass. The small velocity with which a burthened ship approaches a pier-wall or wharf, will crush a boat or small craft which may happen to be in its way. In general, in order that two bodies, A and B, shall have equal *momenta, their velocities must be in the inverse ratio of their masses;* viz. *the greater the mass, the less velocity is required, and* VICE VERSA.*

§ 67. *Uniform Motion.—In order that a body should move with uniform velocity, it is necessary that the power which sets it in motion, should cease to operate the moment it has imparted that velocity.* Then, according to the law

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* If M, V, B, respectively, stand for the momentum, velocity, and bulk, or mass of one body, and m, v, b, respectively, stand for the momentum, velocity and mass of another, then the principles contained in § 65 and § 66 may be expressed mathematically in the following manner:—

$$M : m :: V \times B : v \times b \text{; and}$$

$$V : v :: \frac{M}{B} : \frac{m}{b}.$$

of inertia (see § 58, page 50), the body would continue to move in a straight line, with the same velocity, until, by the operation of some new cause, its motion is either changed or entirely arrested. Instances of this motion have already been given under the head of *Inertia.*

ACCELERATED MOTION. GRAVITY.

§ 68. *Definition of an Accelerating Power.* If the power which sets a body in motion continues to operate in the same direction, during the following intervals of time, it must necessarily continue to increase the velocity of the body. Such a power is then called an *accelerating power;* and the motion resulting from it, an *accelerated motion.*

§ 69. *Uniformly Accelerated Motion.* If the velocities thus imparted increase in proportion to the times, that is, if an equal increase of velocity corresponds to equal intervals of time, then there will result an *uniformly accelerated motion;* and the power which produces it is termed a *uniformly accelerating power.*

§ 70. The most remarkable uniformly accelerating power, and that which more or less influences all mechanical operations in nature, is gravity. (See § 19, page 21.) It will be proper, therefore, to begin with investigating its laws; it being understood, that the same principles will hold true with regard to any other uniformly accelerating power we may find in nature.

§ 71. *Gravity is a uniformly operating Force.* To satisfy yourself of this truth, you need only take a stone, or any other heavy substance, and place it upon your hand; you will not feel any successive jerks, but *one continued pressure.* Besides, even if there were intervals in the operation of gravity, they could not, on account of their extreme minuteness, affect its laws; much less become the object of our senses.

Thus every body, which is prevented from falling to the earth, exercises a *continued* pressure upon the plane or basis on which it rests, or which prevents it from falling. This pressure has

manifested itself *uninterruptedly*, and in *the same degree*, during the longest periods of human observation; and it cannot, therefore, be doubted but that the force of gravity, of which this pressure is the effect, operates in the same manner.

§ 72. *Laws of Falling Bodies.* The four principal laws of falling bodies, and which are applicable also to every other uniformly accelerated motion, are these:—

1. *The final velocities are in proportion to the times;* that is, *if the velocity, at the beginning of the first second, is* 1, *it will be* 2 *at the beginning of the second,* 3 *at the beginning of the third, and so on.*

This law is evident from the very definition of a uniformly accelerating force; for as it operates in every successive interval of time, it must of course add, in each interval, a new impulse to the body; so that, if a body has been in motion during the intervals of 1, 2, 3, 4, 5, &c. seconds, its corresponding velocities will have been 1, 2, 3, 4, 5, &c.

2. *The space described by a free falling body* (or any other body moved by a uniformly accelerating power) *in a certain time, is always equal to the space through which it would have passed, had it moved uniformly with half the final velocity.* Thus, if a falling body has, at the end of a certain time, the velocity 6, then the space through which it has fallen, is equal to that through which it would have gone, had it *all that time* had the uniform velocity 3.

Fig. 10.

To understand this principle, we need only consider that every increase of velocity causes also the falling through a proportionally greater space. Moreover, it is easily perceived that, at the end of *half* a given interval of time, the velocity of the falling body will only be half as great as at the end of the *whole* interval. This follows from the first principle, that the final velocities are as the times. Now, although the body does not throughout fall with half the final velocity, yet the effect is the same; for what, during the first half interval, it needs towards it, is made up by the successive gains during the second half interval, which propel the body as much beyond the middle velocity, as, during the first half interval, it fell short of it. For an illustration, let us suppose that a body has fallen from A to B. (See the figure.) Then, according to what has been said, its velocity, when arrived at the point *c* (half of A B), will be one half of what it is in B; and when arrived at *d*, it will be as much greater than at *c*, as in *b* it was less than the middle velocity; because *b* and *d* are equally distant from *c* and B respectively.

3. *The spaces through which a body, falling or moving with uniformly accelerated velocity, passes, in a succession of equal intervals, are in proportion to the odd numbers*, 1, 3, 5, 7, 9, &c. Thus, if a body falls, during the first second, through 16 perpendicular feet, it will fall, in the 2d second, through 3 times 16 = 48; in the 3d second, through 5 times 16 = 80 feet; and so on.

To understand this, let us suppose a falling body had, at the beginning of the first second, the velocity 1. Then, according to principle 1st, its velocity must be 2, at the beginning of the 2d or end of the 1st second; consequently, according to principle 2d, the space described in the first second is 1, because it is equal to the space through which it would have fallen uniformly with half the final velocity 2. If the solicitation of gravity ceased now, the body would, in the 2d second, uniformly describe the space 2 (because 2 was its final velocity); but, in the 2d second, it receives the acceleration of 1 (equal to that of the first impulse); consequently the whole space described in the 2d second will be expressed by 3. Again, at the end of the 2d second, the velocity must be double that which it has at the end of the 1st second; consequently, as the velocity, at the end of the 1st second, is 2, that at the end of the 2d second must be 4, and, receiving a new acceleration of 1, the space described in the 3d second will be 5. Continuing this mode of reasoning, we shall find that the velocity, at the end of the 3d second is 6, three times that at the end of the first second. Consequently, if we allow again 1 for the acceleration of gravity, the space described in the 4th second is 7. In like manner, the space described in the 5th second will be 9; that of the 6th second, 11; and so on.

4. *The whole spaces passed through are proportional to the squares of the whole times.* Thus, if a body fall 16 feet in 1 second, it will fall 4 times 16 = 64 in 2 seconds, 9 times 16 = 144 feet in 3 seconds, and so on; because 1, 4, 9, 16, &c., are the squares of 1, 2, 3, 4, &c.

This law follows immediately from the preceding one. (See principle 3d.) For, if the space described or fallen through in the 1st second is 1, and in the 2d 3, then the whole space of the two first seconds is $1+3=4$. If to this we add the space described in the third second, which is 5, we have $1+3+5=9$, for the space described in the three first seconds; the same reasoning will give us $1+3+5+7=16$ for that in the four first seconds, and so on.

Thus, if we write the number of seconds during which a body has been in uniformly accelerated motion in one line, the squares

of these numbers will represent the spaces described respectively in these lines.

1	2	3	4	5	6	7	8	9	10	Times.
1	4	9	16	25	36	49	64	81	100	Spaces.*

The correctness of these laws, although sufficiently plain from the above course of reasoning, may also be proved directly by *actual experiments*. For this purpose *George Atwood's falling machine* is admirably calculated. It consists of an apparatus which we are about to describe, and possesses the advantage of exhibiting all the *laws* of uniformly accelerating motion, by moderating the *quantity* of motion so as to render it observable to the experimenter.

This apparatus consists of a wheel, (see Figure 11), turning on its axle, with as little friction as possible, and having a groove on its edge to receive a string. This wheel is fixed between two perpendicular shafts, as represented in the figure, and the whole is, by a cross-piece, T, and the screws, M and N, fixed to a table, to give the machine more firmness and stability. Over the wheel, in the groove, is placed a fine silk cord, to the ends of which are attached two equal cylindrical weights, A and B, which balance each other in all perpendicular positions; because, the string being continued from A to B, *below* the weights, there will always be equal portions of thread

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* The four laws of uniformly accelerated motion may be expressed mathematically by the following formulas:—

1. Let V, v, represent the final velocities, acquired in the times T, t, respectively; then the first law is expressed by the proportion

$$V : v :: T : t.$$

2. Let V′ represent the final velocity acquired during the time T′, and let S′ stand for the whole space gone through; then the second law is expressed by the equation

$$S' = \frac{V' \times T'}{2}.$$

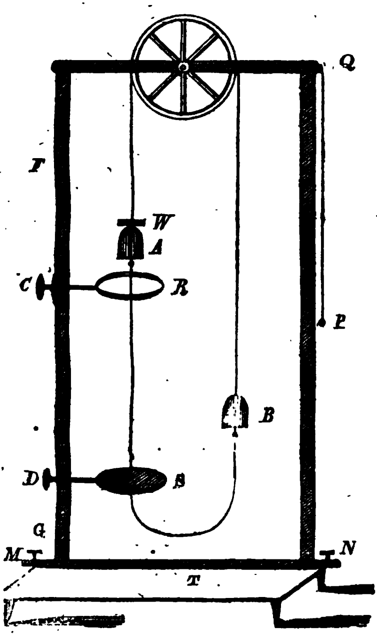
3. If g represents the space through which a body falls in the 1st second, then the space S, through which a body falls in the n^{th} second will be expressed by the equation

$$S = (2n-1) \times g.$$

4. If S, s, represent the spaces described in the whole times T, t, respectively, then the fourth law, which is the foundation of the other three, is expressed by the following proportion:—

$$S : t :: T^2 : t^2.$$

Fig. 11.



on both sides of the wheel.* C and D are two sliding sockets: C terminates in a ring, through which the weight A is allowed to pass; but D supports a stage, which is placed where the experimenter wishes to stop the weight A. W represents a small weight, which is placed, as shown in the figure, upon the weight A when we wish to give it an impulse in the direction of gravity, but, in descending, is left on the ring, R, when the weight passes through it. FG is a scale, divided into inches, halves, and quarters, to measure the descent of the weight, and QP is a pendulum, vibrating seconds, to mark the time employed in the fall.

The advantage and use of this apparatus are easily understood. When the small weight, W, is placed upon A, the *laws* of its descent will indeed be the same as those by which it would be governed during its free fall; but the velocity will be considerably diminished. The whole continued impulse which it receives from gravity, is not solely spent in accelerating its own descent, but, being connected with the two equal weights, A and B, which are always counterpoised, it has to carry these along with it. Hence it is easy to perceive, that, abstracting from the friction of the wheel, the rate of its descent will be to that of its free fall as the weight of W is to the weight of A and B put together. Thus, if A and B together weigh 32 ounces, and the weight W only one ounce, the velocity of its descent will only be $\frac{1}{32}$ of that

* This latter circumstance is neglected in many falling machines used for the purpose of experimenting, and is often the cause of little deviations from those results which we have obtained by mathematical reasoning.

of its free fall, and will consequently be observable with the eye. If the weight of W were only ½ ounce, then the velocity of the descent would only be $\frac{1}{64}$th of that of a free falling body, and so on. It is also plain, that the descent is only accelerated until the weight A passes through the ring R; for then, the weight W being retained by the ring, the weight A will only descend *uniformly* with the final velocity it has acquired at the point R.

The apparatus being now regulated so that the weight W shall only descend one inch in the 1st second (one partition on the scale F G), and the pendulum, PQ, being set in motion, we shall find,

1. That the space through which the weight will descend in the 2d second, will be 3 inches; in the 3d second, 5 inches; in the 4th, 7 inches, and so on; consequently that the WHOLE spaces described by the accelerated descent in 1, 2, 3, 4, &c. seconds, will be as the squares $1+3=4, 1+3+5=9, 1+3+5+9=16$, and so on.

2. If the ring be placed at the mark 2, which is the distance to which the weight W will have descended in the 1st second, we shall find, that the weight A, after W is retained by the ring, will descend uniformly through 2 inches in the 2d second of time; which is easily ascertained by placing the stage at the mark 3, and observing whether the weight A strikes it simultaneously with the vibration of the pendulum. If the ring be placed at the mark 4, to which the weight W will descend in two seconds, then, in the next two seconds, the weight A will uniformly descend through the space of 8 inches. If the ring be placed at the mark 9, to which the weight W will descend in the first three seconds, then, in the following three seconds, the weight A, alone, will uniformly descend through 18 inches (3×6 seconds), and so on. These experiments establish the second and first laws of uniformly accelerated motion, viz. *that the space gone through in any particular time is exactly equal to that which the same body would have described uniformly with half the final velocity*; because 1 is one half of 2, 4 is one half of 8, 9 is one half of 18, &c.;—and *that the final velocities are as the times*; because, at the end of the 1st second, it is 2; at the end of the 2d, 4; at the end of the 3d, 6; and so on; which numbers are in proportion as 1 is to 2, to 3, &c.

§ 73. *Application of the Laws of Gravity.* With the assistance of the laws developed in the last section, we can find the space through which a body falls in a given number of seconds, if the space through which it falls in 1 second is known. This is, according to the nicest calculation, 16 feet and 1 inch, or, more accurately, 193.09 inches, in the latitude of London; but for most calculations, we may call it 16 feet, which is sufficiently near the truth.

Suppose we knew a body had fallen freely during the time of 5 seconds; we should find its perpendicular descent by multiplying 16 by the square of 5; thus, $16 \times 25 = 400$ feet. In general, *we obtain a body's perpendicular descent, by multiplying the number* 16 *by the square of the time expressed in seconds.* Again, if the space fallen through is known, *we can find the time by dividing that space by* 16, *and extracting the square root of the quotient.* Thus, if a body had fallen through 400 feet, by dividing 400 by 16, and extracting the square root of the quotient, which is 25, we should obtain $\sqrt{25} = 5$ seconds, for the time of its descent.*

The laws of free falling bodies explain a multitude of phenomena in nature, and a variety of processes in the mechanic arts. Every one must have noticed the fact, that even small bodies, when falling from a considerable height, acquire a momentum which endangers the safety and life of a person whom they may happen to strike: a rock, rolling down from a precipice, crushes any object which it meets on its way; a person falling or jumping from a considerable height, will dash himself to pieces by the momentum which his body acquires during the descent, &c. If a blow is given with a hammer, the head is raised to some height to give it additional momentum or force by the descent. Where the force of a common hammer is not sufficient for the required effect, as is, for instance, the case when piles or posts are to be driven into the ground, it is customary to raise a heavy block, by means of a capstan, to a certain height, from which it is afterwards precipitated. The construction of the French guillotine is on the same principle. Similar machines are used in the working of metals, and for other technical purposes. The smaller the body is, which is thus to produce a certain effect by its perpendicular fall, the greater must be the height to which it must previously be raised. Thus we can conceive a cannon ball raised to such a height, that the momentum acquired during its perpendicular fall, may even surpass that which it has when fired from the cannon.

§ 74. *The Laws of Gravity are independent of the Mass of Bodies.—The mass of a body has no influence upon, and*

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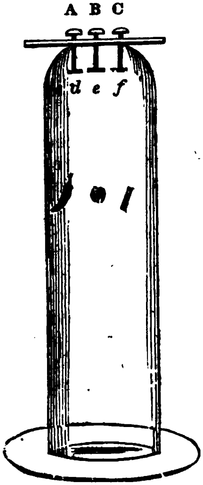
* Let S represent the space through which a body falls in a given time; g, the space through which it falls in 1 second; and T, the time of its falling, expressed in seconds; and we shall have

$$S = g\,T^2$$

$$T^2 = \frac{S}{g}; \text{ and } T = \sqrt{\frac{S}{g}}.$$

does in no way modify the laws of falling bodies. This is self-evident. A number of balls, of the same substance, let fall at the same time, from the same height, will at the same time arrive at the surface of the earth, whether they be let fall one by one, or connected together in a single mass; because every particle of matter is equally attracted by gravity, and every heavy body may be considered as an assemblage of little masses, kept together by the attraction of cohesion. (Chapter 1, § 18.) Besides, *experiments* have shown that the falling of all bodies is equally accelerated by gravity, and that all differences in time and velocity are solely attributable to the resistance of the atmosphere, which a smaller mass (whose momentum is consequently smaller also) is less capable of overcoming than a body of more bulk.

Fig. 12.



If a feather, a piece of wood, and a piece of gold, are suffered to fall from equal heights in the receiver of an air-pump (Fig. 12), from which the air has been previously exhausted, they will all reach the bottom at the same time. The air-pump is an apparatus which we shall describe when treating of the atmosphere, and is used for exhausting the air from a vessel. A, B, C, are screws, fitting air-tight to the receiver represented in the figure; *d*, *e*, *f*, are stages, upon which the different bodies to be experimented upon are placed, and from which they are simultaneously precipitated by a single turn of the screws. These experiments prove that the fall of all bodies is equally accelerated by gravity, as soon as the resistance of air is removed; but we shall soon be able to give a still more satisfactory evidence of this truth, when treating of the oscillation of a pendulum.

§ 75. *Law of Motion of a perpendicularly ascending Body. For the same reason that gravity* ACCELERATES *the velocity of a* FALLING *body, it* RETARDS *that of a perpendicularly* ASCENDING *one, in every successive moment of its ascent, until it becomes zero: then the body will return to the earth, and*

acquire during its fall the same velocity which it had at the first moment of its ascent.

Thus, if a heavy body be projected perpendicularly up into the air, say with a velocity of 240 feet per second, then, in the first second, instead of ascending 240 feet, it will only ascend 240 less 16 = 224 feet; because it falls 16 feet, according to the laws of gravity, independent of the resistance of the atmosphere. In the 2d second, it will rise only 240 less 48 = 192 feet, because it will fall 48 feet. In the 3d second, it will only rise 240 less 80 = 160 feet; in the 4th second, only 240 less 112 = 128 feet; in the 5th second, only 240 less 144 = 96 feet; in the 6th second, only 240 less 176 = 64 feet; in the 7th second, only 240 less 208 = 32 feet: finally, in the 8th second, it will rise 240 less 240 feet; that is, it will rise just as much as it will again descend in that second. The body is now at a height of 896 feet, when it begins its perpendicular descent; and, falling 16 feet in the first second, 48 in the second, 80 in the third, and so on, it will need as many seconds to reach the ground as it ascended in the air, and will, on reaching it, have the final velocity 240, which it has at the beginning of its perpendicular ascent.

By the use of mathematical characters, + for *plus* or *more*, — for *minus* or *less*, × for *multiplied by*, and = for *equal*, we shall be able to express the perpendicular ascent and descent of the body in the following manner:—

Rise of the Body.		*Fall of the Body.*
240 — 16 = 224 feet.	1st second	16 × 1 = 16 feet.
240 — 48 = 192 "	2d second	16 × 3 = 48 "
240 — 80 = 160 "	3d second	16 × 5 = 80 "
240 — 112 = 128 "	4th second	16 × 7 = 112 "
240 — 144 = 96 "	5th second	16 × 9 = 144 "
240 — 176 = 64 "	6th second	16 × 11 = 176 "
240 — 208 = 32 "	7th second	16 × 13 = 208 "
240 — 240 = 0 "	8th second	16 × 15 = 240 "

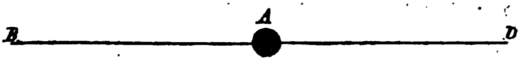
The whole time from the beginning of the ascent until it again reaches the ground, is sixteen seconds.

The laws of motion of a body thrown up under an angle with the horizon, we shall explain after treating of the resolution and composition of forces.

COMPOUND MOTION.—RESOLUTION AND COMPOSITION OF FORCES.

§ 76. *Equilibrium of Forces.—Difference of Forces in opposite Directions.* A body solicited at the same time by two equal opposite forces, remains in the state of rest: the two forces cancel each other, and are said to be *in equilibrium.* If the two forces which operate upon the body at the same time are unequal, then it will follow the impulse of the greater, and receive a *velocity equal to the difference of the two forces.*

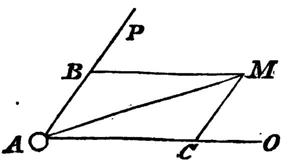
Fig. 13.



Thus, if a body, A (see the figure), receives, at the same time, two *equal* impulses, one in the direction from A to D, and the other in that of A to B, it is evident that no motion can take place, because the two opposite forces are in *equilibrium,* and the effect is the same as if no power had operated upon A. But if the force which gives the body A an impulse in the direction AD, is represented by 7, and that which gives it an impulse from A to B by 5, then the body will only move from A towards D with the velocity which a single power, 2 (the difference between 7 and 5), would have imparted to it.

§ 77. *If the directions of the two forces which solicit the body at the same time make an angle with each other, then the body will describe the diagonal of a parallelogram, whose sides are proportional to the spaces through which the body would have passed in the same time, following the simple impulses of each of these forces.*

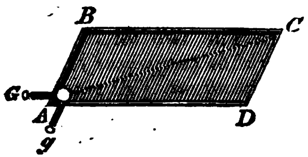
Fig. 14.



If the two forces which simultaneously act upon a body, A (see Fig. 14), make an angle with each other, so that one gives the body an impulse in the direction AP, whilst the other impels it in the direction AO, then it is evident that the body A cannot follow either impulse; but

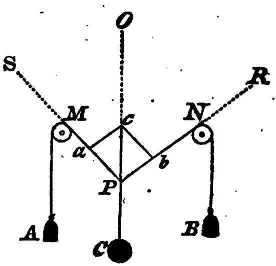
must move in a straight line, AM, between the direction AP and AO of the two forces. To determine the position of the line AM, with regard to AP and AO, let us suppose that, by virtue of the first force, the body ought to move from A to B; and that, following the impulse of the second, it ought to move in the same time from A to C. To follow both impulses, the body A must, at the end of the same time, be in a point, M, which is as far from the direction AO as the first force would have driven it, and as far from AP as the second force would have moved it. This is accomplished when the body is in M. The line AM, therefore, is the diagonal of the parallelogram ABMC, because BM is equal to AC, and MC is equal to AC.

Fig. 15.



The following EXPERIMENT agrees perfectly with this course of reasoning. Take a level table, in the form of a parallelogram, and provide it with a ledge to prevent a ball from rolling off; and let two spring guns, G, *g*, be placed in A, so that when G strikes the ball, it shall move along the side AD in a certain time, and when *g* strikes it, it shall move in the same time along AB. Now, if both guns strike the ball at the same instant, it will move along the diagonal AC in exactly the same time, as, by the impulse of each gun separately, it moved along the sides.*

Fig. 16.



We shall now give ANOTHER EXPERIMENT, taken from Lardner's Mechanics, which proves, in a manner still more direct, the above theory of the parallelogram of forces. Let two small wheels, M, N (Fig. 16), with grooves in their edges to receive a thread, be attached to an upright board or a wall. Let a thread be passed over them, having weights, A and B, hooked upon loops on its extremities. From any part, P, of the thread, between the wheels, let a weight, C, be suspended: it will draw the thread downwards so as to form an angle, MPN, and the apparatus will settle itself at rest in some determined position. In this state, it is evident, that, since the weight C, acting in the direction PC, balances the

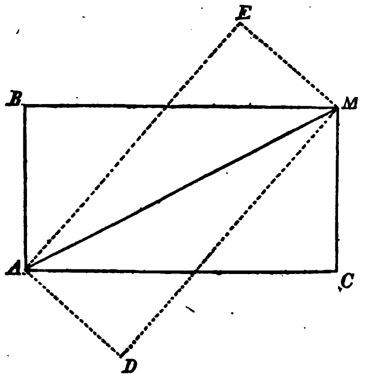
* Library of Useful Knowledge, treatise on Mechanics.

weights A and B, acting in the directions PM and PN, these two forces must be equivalent to a force equal to the weight C, and acting directly upwards from P. To ascertain how far this agrees with the parallelogram of forces, draw a line, PO, upon the upright board, following the direction of PC, and, at the same time, also the lines PR, PS, directly under the threads MP, NP, and following their directions; from the point P, on the line PO, take as many inches as there are ounces in the weight C. Let the part of PO thus measured be P*c*, and from *c* draw *ca* parallel to PN, and *cb* parallel to PM; then, if the sides P*a* and P*b* of the parallelogram thus formed, are measured, it will be found that P*a* will consist of as many inches as there are ounces in the weight A, and P*b* of as many inches as there are ounces in the weight B.

§ 78. The motion which we have just considered (§ 77) is called a *compound* motion. The two forces, AB and AC (Fig. 14), are called the *lateral* or *component forces*, and AM is called the *diagonal* or *resultant*. *A single force, namely, equal to produce the motion* AM, *would carry the body in the same time as far as the two forces* AB *and* AC *together.* From this principle it follows that *every single motion may mechanically be considered as the resultant of two motions, in directions expressed by the sides of a parallelogram whose diagonal represents the single motion.* This process is called the *resolution* of forces, in opposition to the process first described, which is called the *composition* of forces.

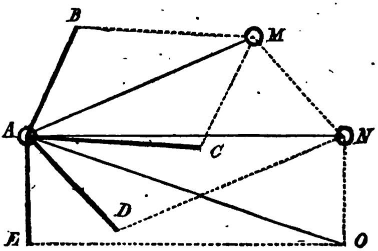
Thus the force AM may be considered as the *resultant* of the two forces AB and AC; because ABMC is a parallelogram; or it may also be considered as the resultant of the two forces expressed by AE and AD, because AEMD is also a parallelogram; and so on. In the first case, AB and AC, and in the second, AE and AD, are the *components*, or *lateral* forces, to which the resultant AM is equivalent.

Fig. 17.



§ 79. The principle of the resolution and composition of forces can equally be applied to three, four, and more lateral forces acting on the same point, as will be seen from the following EXAMPLE:—Let BA, CA, DA, and EA, represent four lateral forces; it is required to find the *resultant*.

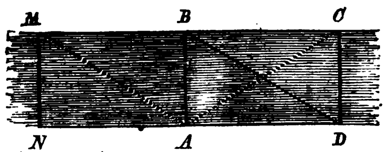
Fig. 18.



SOLUTION. From B draw the line BM parallel to AC, and from C, the line CM parallel to AB; the diagonal AM is the resultant of the two forces BA and CA. Again, from the point M, draw MN parallel to AD, and DN parallel to AM; the diagonal AN will be the resultant of the three forces BA, CA, DA. Finally, from the point N, draw NO parallel to AE, and from E, EO parallel to AN; the diagonal AO will be the resultant of all four forces, BA, CA, DA, and EA; and in the same manner may the resultant of five, six, and more components be found.

Examples of Composition and Resolution of Forces from Nature. When a boat is rowed across a river which has a current, it is impelled by two forces, and will describe the diagonal of a parallelogram, whose sides may be represented by the rapidity of the current, and the impetus given to the boat by the oars. Thus, suppose a boat starts from the point A, and is impelled by the oars in the direction AB, so that, if there were no current, it would reach the point B in one hour; but the current of the river is such, that, without the oars, the boat would float down the river in one hour to the point D; then the resultant of these two forces will be the diagonal AC, in which direction the boat would be impelled by the joint action of the current and the oars. If the boatmen wished to land at the point B, then they would have to row in the direction AM, making for the point M, which is just

Fig. 19.



as far from the point B, as A is from D; because, in this case, AB is the resultant, being the diagonal of the parallelogram AMBD, formed by the component forces AM and AD.—The wind and tide acting upon a vessel, is an instance of a similar kind of motion, in which the resultant is found as in the last example. A ship steering in one direction, and carried in another by the wind, is another instance of the same kind. The flying of a kite is also a motion resultant from the joint action of gravity, which draws the body downwards, and the current of the air, which gives it a horizontal impulse. Most of the equestrian feats are performed on the same principle. The performance of a horseman leaping over a garter is even easier than to leap over it from the ground. In the latter case, the performer must make a double effort, to *rise*, and to project his body forward; but in the first case, he need only give himself an impulse directly upward, the projective motion being already communicated to him by the motion of the horse. Suppose the rider stands upon the saddle of the horse in A, (see the figure), and that the highest point to be cleared is G; then it will only be necessary for him to give himself an impulse which would carry him perpendicularly to the point C, in order to alight again on the saddle of the horse in the point B. To comprehend this, we need only consider that, whilst he rises in the direction AC, his body retains yet the motion of the horse in the direction AM (§ 58, page 50): his body therefore will move in the diagonal AG, the resultant of the two impulses AC and AM: when in G, his body is, by the attraction of gravity, urged downwards in the direction GM; but, retaining still the projective motion communicated to him by the horse, he is obliged to descend in the diagonal GB, which is the resultant of the two forces GD and GM.

Fig. 20.

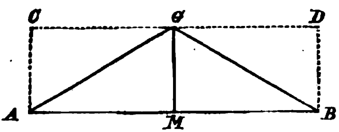
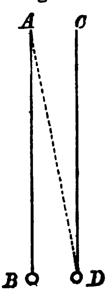


Fig. 21.

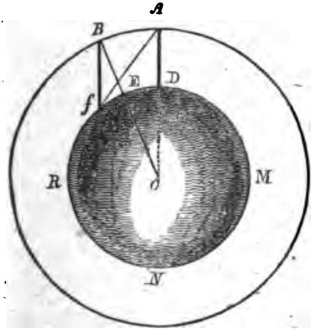


The falling of a heavy body from the topmast of a vessel, is an example of the *composition* of forces. Suppose AB to be the mast, and a heavy body falling from A; it might be expected that the body would reach the deck at a considerable distance behind the foot of the mast, since the vessel, during the descent of the body, has been moved onwards by the sails. This, however, is not the case: on the contrary, the body will fall at the *foot* of the mast, in exactly the same way as if the ship had not been in motion. This is, indeed, easily understood. When the body A is left free, it has yet, in common with the mast, the progressive motion from A to C; and being, at the same time, attracted perpendicular-

ly downwards, it is obliged to describe the diagonal AD. But when the body arrives in D, the mast, in common with the ship, has moved from B to D; consequently, notwithstanding the oblique motion of the body D, it will appear to a person on deck as though it descended in a perpendicular line, following the direction of gravity.

We will conclude these observations with mentioning one more important instance of the composition of motion, which is, at the same time, a proof of the diurnal rotation of the earth on its axis. It consists in the descent of a heavy body from an elevation of several hundred feet. To understand this motion, we will first consider the position of such a body before its descent.

Fig. 22.



For this purpose, let NRDM represent the equator of the earth, or one of its parallel circles, C its centre, and let AD be a tower, or some other high eminence, on its surface. It is evident, that, by the rotation of the earth on its axis, the point A, at the top, will receive a greater velocity than the point D (at the foot of the tower), since A will move from A to B in the same time in which D moves to E; and the arc AB is evidently greater than DE, because it is described with a greater radius. Now, let a heavy body fall from the top, A, of the tower AD, and let us suppose that the rotation of the earth during its descent, is from D to E; then the body A, in the first moment of its descent, will be actuated by two forces, one which impels it in the direction AD, and the other which gives it an impulse in the direction from A to B. The body must, therefore, describe the diagonal A*f*, and arrive in a point *f*, just as much *before* the tower (which, during the fall of the body, will have moved to the point E) as the velocity AB, at the top, is greater than that at the bottom, DE. Experiments of this kind have actually been made in calm days, by suffering heavy bodies to descend from the top of the tower of Pisa in Italy, and the same experiments have been repeated by Professor Bohnenberger, of the university of Tübingen, in a perpendicular descent of 600 feet into a mine; and the results agreed, as well as the nature of the experiments permitted, with the computed velocity of the earth's rotation on its axis.

APPLICATION OF THE COMPOSITION AND RESOLUTION OF FORCES TO THE THEORY OF CURVILINEAR MOTION.

§ 80. When the body A (Fig. 23) receives an impulse in the direction AP, it ought, according to the law of inertia (§ 58, page 50), to continue to move in that direction, and describe the straight line AP. But if, at the same time,

Fig. 23.

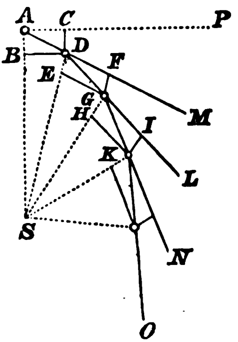
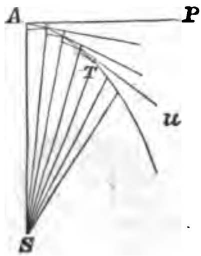


Fig. 24.



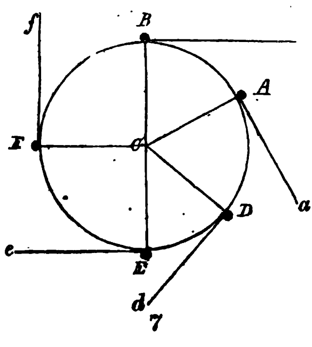
there is a power in S, attracting the body A in the direction AS, then, according to what has been said (§ 77), the body A will describe a diagonal, AD, whose sides, AC and AB, are in proportion to the two forces P and S, and would continue in the direction ADM, if it were not again solicited by either of these forces. If in D the attractive force S urges the body again towards S, then the body will describe a new diagonal, DG, whose sides are now in proportion to the forces which urge the body in the two directions DM and DS. If the force S is again operating in G, then the body will describe a new diagonal, GK; and in the same manner may a fourth, fifth, and sixth diagonal be described. The smaller the intervals are, with which the attractive force S acts on the body A, the smaller will be the diagonals, AD, DG, GK, &c.; finally, when the force S operates *continually*, the body A will, in every moment of its motion, be turned from its direction, and describe a curve line, which is represented in Fig. 24.

§ 81. *A force which attracts a body continually towards one and the same point, is called a* CENTRIPETAL *force; and that which incessantly urges it to remove from that point, in a straight line, is termed a* CENTRIFUGAL *or* TANGENTIAL *force; both forces together are termed* CENTRAL FORCES. If, at any time, one of those powers ceased to operate, the body would solely obey the impulse of the other. Supposing, for instance, that this takes place when the body is in T (Fig. 24), then, if the centripetal force remained, the body will move to the point S, and its motion will be a uniformly accelerated one, similar to that of a falling body; but if the centrifugal force remained, then the body would remove from the point S, and go on forever in the straight line T*u*.

REMARK. The nature of the curve line, resulting from the joint action of central forces, depends upon the ratio which the centripetal force bears to the centrifugal force. If the impulses of the centripetal force are inversely as the squares of those of the centrifugal force, then the body describes an ellipse. This is the case with the planets of our solar system, which, in consequence of their being continually attracted by the sun, and having received, from the hand of the Creator, an impulse to hurry them, in a straight line, into infinite space, are forced to describe elliptical orbits. In the same manner does the moon gravitate round the earth, and every satellite round its planet, by which it is attracted. But of this we shall say more in the following paragraphs.

§ 82. *Circular Motion.* Although the attraction of gravitation is the principal centripetal force in nature, yet there are a variety of other forces which may be substituted in its place. Thus if a ball, A, attached to a string, AC, is whirled round in the direction ADEF, the string, AC, acts as the centripetal force, which will manifest itself by tension, and the tangential or centrifugal force will be exhibited by the directions of the tangents A*a*, D*d*, E*e*, &c.; for

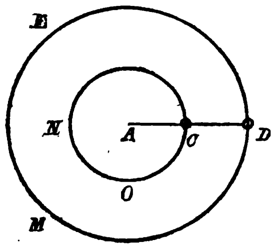
Fig. 25.



if, at any time whilst the ball is whirling round, the string, AC, is cut or let loose, the ball will always fly off in straight lines, which are tangents to the circle of revolution. *The centrifugal force increases with the velocity of the revolution, and the greater the sweep of the curve, that is, the greater the radius,* AC, *of the curvature, the greater is the velocity, and, consequently, also, the centrifugal force produced by it.*

Thus if the string, AC, were twice as long, and the body revolving, as before, the velocity, and consequently, also, the centrifugal force, would be double of what it is in our last example. This will soon be understood from the following consideration: When the radius AD is equal to twice AC, then the exterior curve, DEMD, is also twice as large as the curve CNOC, described with the smaller radius, AC; because the circumferences of circles are in proportion to their radii, and, being described *in the same time,* it is evident, that the velocity of the body D must be as great again as that of the body C.

Fig. 26.



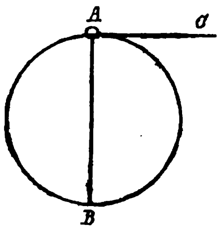
§ 83. If, instead of the string, AC (see figure), a *solid* hinderance were substituted, to prevent the body C from flying off in a straight line, then this would equally replace the *centripetal* force. If a heavy body be attached to the edge of a circular piece of card or board, which revolves on its centre, then this body will be circumstanced as in the preceding example. The cohesive attraction of the card or board will replace the centripetal force, and the centrifugal force will be proportioned to the velocity of the revolution. *A straight line, passing perpendicularly through the centre of such a revolving body, is called the* AXIS OF REVOLUTION, *and the body itself is said to* TURN ON ITS AXIS.

A wheel turning on its axletree is an instance of this kind. The axletree is, in this case, the axis of revolution, and the spokes represent the centripetal force. By the rotation of the wheel, every part of the rim receives, by the centrifugal force, an impulse to fly off in a straight line, from which it is prevented by the exterior iron hoop, called the *tire*. The greater the circumference of the wheel, the stronger must be the tire; because the

increased centrifugal force acting on each point of the rim, every part of it will have a stronger tendency to fly off in a straight line.

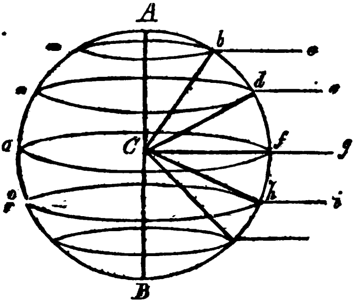
Examples of the joint Action of Centrifugal and Centripetal Force from Nature. A person, wishing to fling a stone to a considerable distance, makes his arm revolve, to give the stone an additional impetus by the centrifugal force. On the same principle did the ancients fling stones from swings, which were first hurled round in the air. A stone, or any other heavy body, placed in a hoop which is rapidly whirled round, will not fall to the ground, even when its position, as represented in the figure, is perpendicular to the ground. In this case, the centrifugal force in the direction AC is so great as to overcome, completely, the attraction of gravity downwards, and the body A, being, by the hoop, prevented from flying off in a straight line, will remain in its place as long as the hoop is revolving. The same will take place, if, instead of the heavy body, a tumbler, filled with water, be substituted; but the water will, in this case, rise on one side of the tumbler, because the particles of the liquid are, by the centrifugal force, driven from the centre to the circumference. When a grindstone is rapidly turned round, the water is seen to fly off in straight lines; and the same takes place with the mud which is thrown off from the wheels of a carriage. When a person turns rapidly round a corner, his body, receiving, by the centrifugal force, an impulse in a straight line, is apt to fall, unless this impulse in counteracted by inclining the body toward the corner. Carriages and other vehicles, which cannot, of themselves, counteract the influence of the centrifugal force, ought, on this account, to be turned slowly, else they will be overset in the direction from the corner. For the same reason do the riders and horses, in equestrian feats, turn their bodies toward the centre of the ring, in which these performances generally take place, in order that their weight inwards may be a counterpoise to the centrifugal force, which impels them in a contrary direction.

Fig. 27.



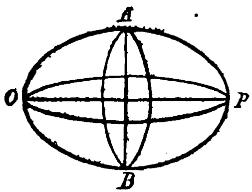
But the most remarkable instance of the action of the centrifugal force is exhibited by the rotation of our globe on its axis.

Fig. 28.



Let AB (Fig. 28) represent the earth's axis, *of*, the equator, and *nd*, *mb*, different parallel circles. It is evident, that, during the revolution, each particle of matter, of which our globe is composed, is forced into a circular motion, the centre of which lies in the axis AB; but the equator, *of*, being the largest circle, the centrifugal force will be greatest in the circle *of*, and diminish toward the poles, A and B. The result of this unequal action of the centrifugal force is exhibited in the form of our earth, which is spheroidical, as represented in figure 29, the parts near the equator, OP, being, by the centrifugal force, actually driven from the centre. The centrifugal force, which thus acts on every particle of our globe, is equally active with regard to detached bodies on its surface; all which have a tendency to fly off in straight lines, *bc*, *de*, *fg*. (Fig. 28.) The centripetal force, which prevents this motion, is the attraction of gravity, which, however, is slightly modified, for two reasons; first, because the centrifugal force is greatest on the equator, and diminishes towards the poles; and, secondly, because the centrifugal force *fg*, on the equator, acts directly *opposite* to the direction of gravity represented by CF, and more and more *angular* as it approaches the poles, which is evident from the figure; the angles C*de*, C*bc*, &c., becoming more and more acute, as the points *d*, *b*, &c., approach the poles; and at the poles A and B themselves, where the centrifugal force is zero, the attraction of gravity will have reached its maximum. These facts have been established by actual observations and experiments, which we shall mention, when treating of the oscillations of a pendulum.

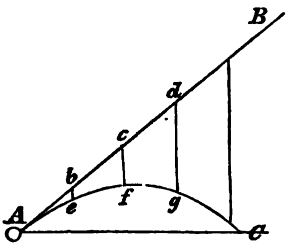
Fig. 29.



FURTHER APPLICATIONS OF THE THEORY OF COMPOSITION AND RESOLUTION OF FORCES TO THE CURVILINEAR MOTION OF A BODY THROWN AT AN ANGLE WITH THE DIRECTION OF GRAVITY.

§ 84. *If a body is thrown up in a direction* AB (see the figure), ***making, with the horizontal line*** AC, ***any angle you please, it cannot continue its way in the same direction; because it is, in every moment of its rise, attracted downwards by gravity; it must therefore describe a curve line, which, in mathematics, is termed a*** **PARABOLA.**

Fig. 30.



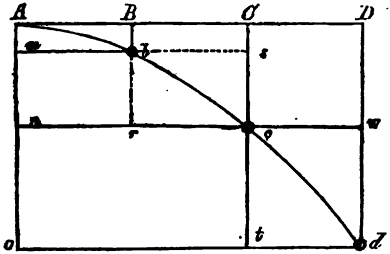
Suppose the velocity imparted at the point of starting impels the body through a space = A *b*, in one second. Then, if it were not acted upon by any other power, it would, at the end of the 2d second, be in *c*; at the end of the 3d second, in *d*; and so on (taking *ab*, *bc*, *cd*, &c., to be all equal to one another). But being, in every moment of its motion, solicited by gravity, it will, at the end of the 1st second, be as many perpendicular feet below the point *b*, as it would have freely fallen through in that time, namely, 16; at the end of the 2d second, it will be 4 times 16 = 64 feet below the point *c*; at the end of the 3d, 9 times 16 = 144 feet below *d*; &c. *Thus the body describes a curve line, which, when geometrically examined, is found to be a parabola.**

§ 85. *If a heavy body is projected horizontally, that is, at right angles with the direction of gravity, then, whatever be its velocity, it will come to the ground in exactly the same time which it would need for its perpendicular descent.* Let Fig. 31 be the heavy body, raised, for the sake of an example, to a height of 144 feet, and let it be projected in the direction AD. Let AB represent the distance to which it is thrown in one second, and let A*m*, A*n*, and A*o*, respectively,

* Because the squares of the ordinates are in proportion to the abscissas.

represent the spaces of 16, 64 and 144 feet, through which every heavy body falls, in the time of 1, 2, 3 seconds. It is evident that the motion of the body A, in the first second, is compounded of two lateral forces, A*m* and AB, in consequence of which, it must describe the diagonal A*b*, in the same time which it would have needed to move from A to

Fig. 31.



B, or to fall from A to *m*. In like manner is its motion, during the 2d second, compounded of the two lateral forces, *br* and *bs*, the 1st of which represents the perpendicular fall, and the 2d, the projectile force: it will, therefore, describe the diagonal *bc*. Finally, during the 3d second, it must obey the laws of gravity, and fall through *ct* (equal to *no*); but, at the same time, also, it will obey the projectile force *cw* (equal to CD), and will be on the ground at *d*, in exactly the same time in which it would have completed its perpendicular descent, A*o*.

Although, in this example, we have only chosen a height of 144 feet, yet it is easily perceived, that the same course of reasoning will equally hold with regard to any eminence from which a projectile may be thrown; so that, if this be done *horizontally*, it will always reach the ground in exactly the same time in which it would have fallen perpendicularly, when solely solicited by gravity.

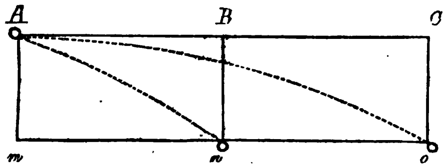
The diagonals A*b*, *bc*, *cd*, are, strictly speaking, curve lines; because the body A is, in every moment of its motion, deflected from a right line. The attraction of gravity from the centre of the earth, acts as the centripetal force, and the projectile impulse of the body takes the place of the centrifugal. The whole motion is analogous to that described in § 80, and the same reasoning applies equally to it.

§ 86. *The distance to which a projectile may be thrown,*

does not only increase with the horizontal velocity, but also with the height from which it is thrown.

That the sweep of the curve increases with the velocity of the projectile, is self evident.

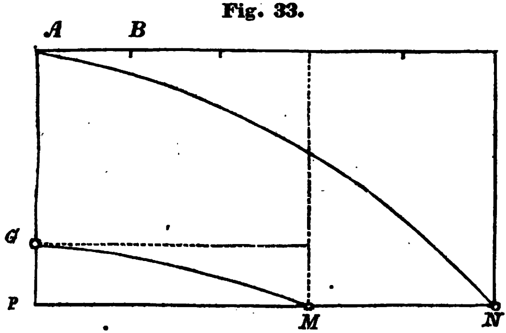
Fig. 32.



Let two bodies be thrown horizontally from the same eminence, Am = 16 feet, one with the velocity AB per second, and the other with the velocity AC; both will reach the ground at the same time; but whilst the first body arrives in n, the other arrives in o, exactly as many feet farther from m, as the velocity AC is greater than AB.

Again, let us suppose that two bodies, M and N, (Fig. 33), are both thrown with the same velocity, but from unequal heights. Let the height from which M is thrown be 144 feet, and that from which N is projected, 400 feet; then the body M will descend to the ground in three seconds, and the body N in 5 seconds (according to the laws of free falling bodies, page 59). Now,

Fig. 33.



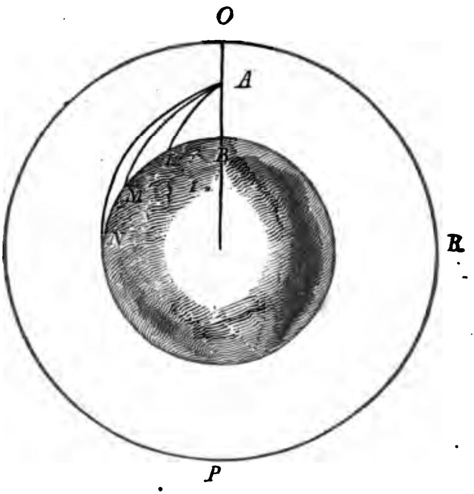
suppose that AB is the distance to which each of these bodies is projected in one second; then, according to what we have proved in § 85, the body M, which is thrown from G, will reach the ground in 3 seconds, and arrive in M at a distance MP, equal to three times AB; whereas the body N will be 5 seconds in the air, and arrive at N, making the distance PN equal to five times AB. *Hence we infer, that when the velocities are equal,*

the distances PM *and* PN, *to which the bodies* M *and* N *are thrown, are in direct proportion to the times needed for their perpendicular descent.*

This principle has been successfully applied to the bombarding of cities (lately in the bombardment of Algiers by the French), it having been found by experiments, that the same quantity of powder projects a ball much farther when it is fired from a cannon standing on an eminence, than from one situated in a plain.

§ 87. If we apply the foregoing principles to the curvilinear motion of projectiles on our globe, we shall at once perceive that (abstractedly from the resistance of the atmosphere) the sweep of the curves AL, AM, AN (Fig. 34),

Fig. 34.



depends entirely on the projectile velocity with which a body is first thrown into space, and on the distance at which it is originally placed from the earth's surface. Hence it is easy to conceive a height, BO (see the figure), from which a body may be hurled with such a projectile velocity as to describe the curve OPRO, which would carry it completely round the earth, and make it return to the point O, whence it departed. In this case, the body would continue to revolve round the earth; because, when returned to the point

O, it retains still its projectile force, and the attraction of gravity, acting upon it as in the first instant, causes it to revolve a second time, and then a third time, and so on.

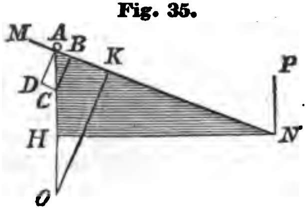
Such is the revolution of the moon round the earth, and such is the revolution of every planet round the sun, from the time they were first launched into space by the hands of the omnipotent Creator, who has traced its orbit to every heavenly body, and from which it cannot deviate without destroying the order and harmony of the mechanics of the universe.

§ 88. We have seen, in the preceding paragraphs, that the curvilinear path of a projectile may be traced, when the intensity of the earth's attraction and its projectile force are known. In like manner, we are able to determine the force of attraction to a common centre, when the velocity of the projectile and its motion are known. Thus, by knowing the moon's orbit and her velocity, we have been able to ascertain the amount of attraction which our earth exercises upon her; and upon comparing it to the intensity of gravity on the earth's surface, it has been found, that the *attraction of gravity decreases in proportion to the squares of the distances.* This law applies equally to the attraction of gravitation of all other heavenly bodies, and expresses, that, if the distances of a body from the centre of gravitation are as the natural numbers 1, 2, 3, 4, 5, &c., the attractions of gravitation will only be 1, $\frac{1}{4}$, $\frac{1}{9}$, $\frac{1}{16}$, $\frac{1}{25}$, &c., respectively. Thus a body placed at 10 times greater distance is only $\frac{1}{100}$ as much attracted; at 20 times greater distance, it is only attracted $\frac{1}{400}$ as much; and so on.

MOTION ON AN INCLINED PLANE.

§ 89. An inclined plane, AN, is one which makes with a horizontal plane any angle at pleasure. If upon this plane you place a heavy body, A, it will be prevented from falling in a vertical direction, AC, but is obliged to slide down the plane MN.

Fig. 35.



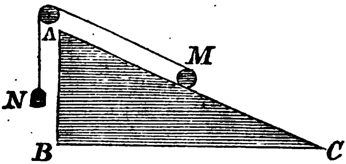
§ 90. *The law of motion on an inclined plane is analogous to that of a free falling body; that is, the motion of a body on an inclined plane is like that of a free falling body, uniformly accelerated; the only difference consists in the velocity, which, on an inclined plane, is naturally smaller than at the perpendicular fall;* (because AB is less than AC, BK less than CO, &c.)

Supposing the body A had, in the 1st second, fallen through a space = AC, then the space described by its motion on the inclined plane is equal to AB; because AC may be considered as the diagonal of two lateral forces (§ 78, page 68), one of which, AB, urges the body down the plane MN, and the other, AD, exercises upon that plane a perpendicular pressure. During the 2d second, the body A would have fallen through a space, CO, three times as great as AC (§ 72, 3dly); hence the corresponding space BK, described on the inclined plane, is three times as great as AB. In like manner, because the body A would, during the 3d second, have fallen through a space five times as great as AC, its motion on the inclined plane will be five times AB; and so on.

§ 91. *Velocity on an Inclined Plane.—Angle of Elevation.—The velocity of a body moving on an inclined plane, depends on the angle of elevation* (ANH) *which the plane* (MN) *makes with the horizontal plane* (HN). The greater this angle is, the more will the velocity on the plane resemble that of a free falling body; finally, when the angle of elevation becomes a *right* angle, HNP (Fig. 35), the plane will be *perpendicular* to the horizon, and the motion will be that of a free falling body. The reverse takes place when the angle of elevation is zero, that is, when the plane MN is *parallel* to the horizon; because then the whole weight of the body is supported, and no motion takes place.

§ 92. *To prevent the motion of a body on an inclined plane, it is necessary that it should be urged in the opposite direction, with a force which is to the weight of the body as AB is to* AC, or as AH is to AN; consequently, with a less force than is required to prevent the perpendicular fall of bodies; because part of the body's weight is supported by the plane. Thus ½ pound in N will be in equilibrium with

Fig. 36.



1 lb. in M (Fig. 36), when AB is half of AC; ⅓ lb. is in equilibrium with 1 lb. in M, when AB is one third of AC: in short, the more the situation of the plane AC approaches that of the horizontal plane BC, the more is the body's weight supported by it; the less force, consequently, is required to prevent its motion. This may be shown by experiments.*

If AB (Fig. 36) is 3 feet, and BC, 5 feet, then, according to the rules of geometry, AC must be 6 feet; and in this case, AB being

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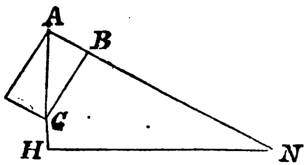
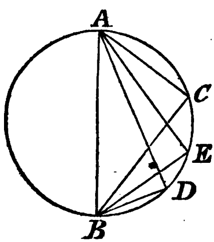
* Those who have studied geometry will easily perceive that the triangle ABC is similar to the whole triangle AHN (having the angle at A common, and both being right-angled, the one in B, and the other in H); therefore we have the proportion

Fig. 37.



AB : AC = AH : AN; that is, *The motion on the inclined plane is to that of a free falling body, as the side* AH *of the right-angled triangle* AHN *is to the hypothenuse* AN. From this proportion it follows, that a body needs as much time to move down the hypothenuse of a right-angled triangle as it needs for the perpendicular fall through one of its sides.

Fig. 38.

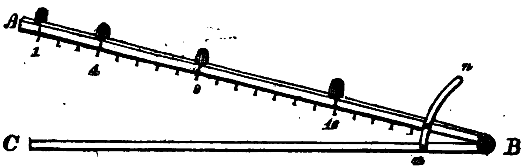


Another remarkable inference which we may draw from this principle is, that a body descends either of the chords AC, AE, AD, in exactly the same time which it would need to fall perpendicularly through the diameter AB; because ACB, AEB, ADB, &c., are right-angled triangles, having for their common hypothenuse the diameter AB. (See Grund's Plane Geometry, Section V. Remark to Problem XVII.)

just $\frac{1}{2}$ of AC, $\frac{1}{2}$ lb. in N will be in equilibrium with 1 lb. in M. Again, if AB is 6 feet, and BC 8 feet, AC will be 10; consequently, AB $\frac{6}{10}$ or $\frac{3}{5}$ of AC. In this case 3 lbs. in N balance 5 in M, &c. If, in either of these experiments, the plane AC be made movable, and capable of turning round the point C, then, by gradually diminishing the angle of elevation, ACB, we shall find that *lesser* weights in N balance the same weight in M; finally, when AC is placed upon BC so as to give the plane AC a horizontal position, no power at all is necessary in M to keep the body N from moving off the plane.

REMARK. The whole theory of motion on an inclined plane, and, consequently, also, that of free falling bodies, to which it is analogous, may be illustrated by an instrument, which, on account of its simplicity and cheapness, may form part of a common school apparatus.

Fig. 39.



It consists of an inclined plane, AB, attached in such a manner to the horizontal beam, CB, that, by means of the inserted iron or brass arc, *mn*, it may receive any inclination you please. This plane is provided with ledges, to prevent the ball from rolling off, or moving down otherwise than in a straight line. The whole of this plane is divided into equal parts, which are marked. At the 1st, 4th, 9th, 16th, &c., of these divisions are bells, with mechanical contrivances, which cause them to be struck, when the ball arrives at these points, without impeding its velocity. Now, if the plane receives an inclination which makes it pass through the first of these divisions in the 1st second, then it will pass through the three next divisions in the 2d second, through the five next in the 3d, and so on; so that the bells are struck regularly at the end of the 2d, 3d, and 4th seconds; which proves the principal law of accelerated motion, viz. that *the whole spaces, described from the beginning of the motion, are as the squares of the times.* Thus, if the times are 1, 2, 3, 4, &c., the spaces are 1, 4, 9, 16, &c. (the divisions on the plane being made accordingly.)

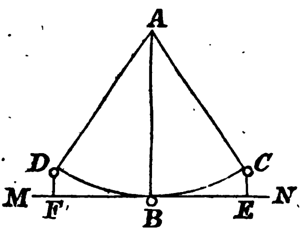
The principal application of the inclined plane is to moderate the velocity of the descent of bodies. For this reason inclined

planes are used in the unloading of goods from wagons. Staircases are inclined planes, although interrupted by steps; and the risk of falling in the attempt of mounting and descending them increases with the angle of elevation, as the position of the principal plane approaches more and more the perpendicular direction of gravity. Of the uses of the inclined plane in the elements of machinery, we shall speak in the next Chapter.

OSCILLATION OF A PENDULUM.

§ 93. If a heavy body, B, is suspended in such a manner that it can freely move round the point of suspension, A, it receives the name of a *pendulum*. A *simple* pendulum is imagined to have but one heavy point, which is suspended by an inflexible straight line. A heavy mass suspended by a very fine thread, or by a hair, may, for most purposes, be considered a simple pendulum.

Fig. 40.



§ 94. If the heavy body, B (see Fig. 40), is raised from its perpendicular direction, AB, to the inclined position AC, and afterwards let free, then, because gravity attracts it downwards, in the perpendicular direction CE, and the string AC prevents it from following that impulse, it will begin to swing in circular arcs, CBD, and would continue to do so, if no obstacle came in its way, to impede or stop its motion. The angle BAC, by which the pendulum at first departs from the perpendicular direction, AB, is called the *angle of oscillation* or *elongation*.

The heavy body, B, will at first describe the arc CB with accelerated velocity; because, in every moment of its descent, gravity operates upon it.* When the body has arrived at the

* These accelerations cannot be uniform; because the nearer the heavy body approaches to the point B, the less does its position vary from the horizontal plane, MN. The whole of the arc BC, namely,

point B, its velocity, which has now arrived at its maximum, does not suffer it to remain there, but forces it, according to the law of inertia, to rise on the other side, and to describe a new arc, BD, which, if nothing impedes the body's motion, must be equal to the arc CB, through which it first descended. When the body is in D, its velocity, which, during its ascent from B to D, has been diminished by gravity, in the same manner in which it was increased during its descent from C to B, is now in precisely the same situation in which it was at first, in the point C; it will therefore return, and describe a new arc, DBC; and then, again, another arc, CBD; and so on. In this manner, the oscillations ought to continue forever; but the resistance of the atmosphere, friction, and the small force which is required to bend the string by which the heavy body is suspended, gradually reduce the arc of oscillation, until the pendulum finally stands still.

§ 95. *Isochronism of a Pendulum.—The most remarkable property of a pendulum consists in the equal duration of its oscillations;* for although, from the circumstances alluded to, the arc of oscillation is continually diminishing, *the duration of one of its oscillations is but very little influenced by the magnitude of the arc;* so that, if this be small, one oscillation will last as long as another.

§ 96. *Time needed for each Oscillation.— The time which is needed for each oscillation depends upon the length of the pendulum.* With regard to this dependency, there exists the following law: *The lengths of any two pendulums are in proportion to the squares of the times needed for one of their respective oscillations.* Thus, of two pendulums, the twice longer will swing four times slower; because it will need four times as much time to perform one oscillation; the three times longer will swing nine times slower; the four times longer, sixteen times slower, &c. This may be shown by experiments.*

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may be considered as consisting of a great number of inclined planes, which, having different inclinations to the horizontal plane, MN, must, of course, change the law of motion of the swinging body, in every moment of its descent. Thus, although the velocity continues to increase, the increase is not uniform.

* If T, t, respectively, represent the times needed for one oscillation, and L, l, the respective lengths of the pendulums, then we have the proportion

$$T^2 : t^2 = L : l;$$

whence,

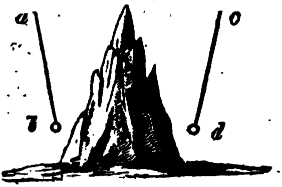
$$T : t = \sqrt{L} : \sqrt{l}.$$

§ 97. *Uses of the Pendulum.* The uses of the pendulum consist,

1st. *In exhibiting the direction of gravity* (when the pendulum is in the state of rest).

2dly. *It shows that great masses influence the attraction of gravity;* because, in the neighborhood of large mountains, the direction of a pendulum differs from a vertical line.

Fig. 41.



This has actually been tried with two pendulums placed at opposite sides of Mont Blanc, in Switzerland, when the directions *ab*, *cd*, were found to deviate from the direction of gravity, as represented in Fig. 41.

3dly. *The pendulum proves that all bodies are equally attracted by gravity;* because pendulums made of different substances, when equally long, swing equally fast.

A pendulum made of lead, and another of the same length made of wood, swing equally fast; which shows that the mass or weight of a body has no influence upon the *velocity* of the fall (compare § 74, page 63), to which the motion of a pendulum is analogous.

The theory of the pendulum proves difficult even to those well versed in the higher branches of mathematics. The most difficult problems are the finding of the time in which the heavy body describes a given portion of the arc, and the determination of the centre of oscillation.

The *whole* duration of an oscillation is nearly equal to

$$\tfrac{1}{2}\pi\sqrt{\frac{2L}{g}} \text{ seconds;}$$

where π stands for the number 3,1415926, L for the length of the pendulum, expressed in feet, and g for the number of feet through which a free falling body falls in the 1st second. This formula enables us to find the space through which a body falls in the 1st second, if the length of the pendulum and the time of its oscillation are known; and by this means the space through which a free falling body falls in the 1st second, may be accurately determined for any latitude. (Compare § 73, page 62.)

4thly. *The pendulum shows that the attraction of gravity is less near the equator than near the poles;* because a pendulum of the same length swings slower near the equator than near the poles.

This property of terrestrial gravity, to which we have already alluded in the remarks to § 83, page 76, was first demonstrated mathematically by Sir Isaac Newton, and has since been verified by experiments with the pendulum, as may be seen by the following table:—

Place of observation.	North latitude.	Length of the pendulum in lines of a Paris foot.	PERPENDICULAR DESCENT of a body in a second of time, inferred from the length of the pendulum, in French feet.
Quito, in South America,	0° 25′	439.10	15.0477
Paris, in France, . . .	48° 50′	440.60	15.0991
Kola, in Lapland, . . .	68° 42′	441.31	15.1235

(See Bode's Knowledge of the Earth, Berlin, 1803, page 180.)

5thly. *Experiments with the pendulum have proved that the attraction of gravity diminishes on the top of high mountains; consequently, that the attraction of gravity diminishes in proportion to the distance from the earth's surface.*

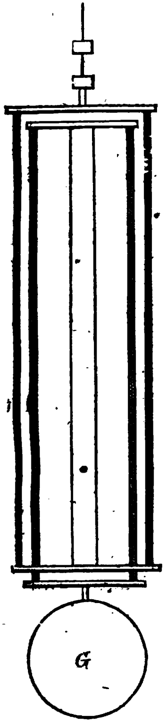
This truth, likewise established by Sir Isaac Newton, by the force of mathematical reasoning, has been verified by *Bouguer*, a French philosopher, who found that the same pendulum which, near the sea-shore, made 98,770 oscillations in twenty-four hours, vibrated but 98,720 times on the top of the mountain *Pichincha*, making a difference of fifty oscillations in one day.

6thly. *The pendulum is the best regulator of a clock;* because the duration of its oscillations are, as nearly as possible, equal to one another.

The isochronism of a pendulum, which was discovered by *Galileo*, was first applied by *Huygens*, a Dutch philosopher, to the regulation of clocks. The only modification to which the velocity of a pendulum is subject, arises from its dilatation or contraction, occasioned by different degrees of temperature.* These, by changing the *length* of the pendulum, must necessarily produce a slight variation in the time needed for an oscillation.

* We shall learn, in the course of this work, that all bodies are dilated by heat, and contract again by cold. (See Chapter VII. on Heat.)

Fig. 42.



To obviate this, various contrivances have been invented, all of which are founded on the unequal expansion of different metals by heat. One of the most common is *Harrison's gridiron pendulum*, represented in Fig. 45. It consists of a combination of brass and steel rods, in such a manner that the expansion of the steel corrects that of the brass, so that the length of the pendulum may be the same at all temperatures. The dark lines in the figure represent the steel rods, and the light lines those of brass. The central rod is fixed, at its lower extremity, to the middle of the third cross-piece from the bottom, and passes freely through holes in the cross-pieces which are above; whilst the other rods are secured, near their extremities, to the cross-pieces, by pins passing through them. In order to render the whole more secure, the bars pass freely through holes made in the two other cross-pieces, the extremities of which are fixed to the exterior steel wires. As different kinds of the same metal vary in their rate of expansion, the pendulum, when finished, may be found, upon trial, to be not duly compensated. In this case, one or more of the cross-pieces are shifted higher or lower upon the bars, and secured by pins passed through fresh holes.*

OF THE LEVER.

§ 98. *Definition of the Lever.* An inflexible straight bar, AB (Fig. 43), supported in one of its points, and capable of moving round that point, is called a *lever*. The point C, in which it is supported, is

Fig. 43.

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* Lardner's Mechanics, Chapter XXI.

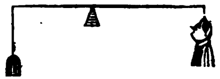
called the *prop* or *fulcrum;* and the parts AC, CB, of the bar, which extend on each side of the prop, are termed the *arms of the lever.*

§ 99. *Power and Weight.* When two forces act upon the lever, in order to distinguish them from one another, we call the one *power*, and the other *weight.*

In all applications of the lever, the *weight* is that which is to be raised, and by the *power* is understood the force which is required to raise the weight.

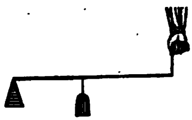
§ 100. *Kinds of Lever.* There are three kinds of levers. The first has the prop between the power and the weight. (Fig. 44.)

Fig. 44.



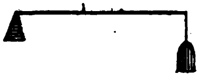
The second has the weight between the prop and the power. (Fig. 45.)

Fig. 45.



The third has the power between the prop and the weight. (Fig. 46.)

Fig. 46.



§ 101. *Law of the Lever.* The principal law of the lever is this: *The power is to the weight inversely as the distances from the fulcrum; that is, the smaller the power is, which shall be in equilibrium with the weight, the greater must be its distance from the fulcrum.* Thus a power of 1 lb. is in equilibrium with a weight of 2 lbs., when its distance from the fulcrum is double the distance of the weight: if its distance is three times as great as that of the weight, it will be in equilibrium with 3 lbs.; and so on. This may be clearly shown by experiments. The product of the power or the

weight by the distance of the fulcrum is called *moment.* Hence the above law may also be expressed in this manner:—*The power is in equilibrium with the weight, when its moment is equal to the moment of the weight.*

Fig. 47.

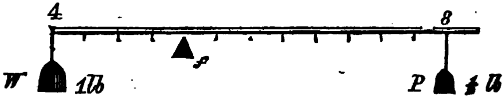


Fig. 48.

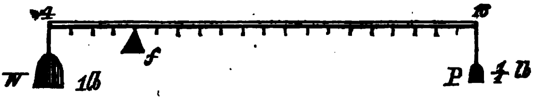


Fig. 49.

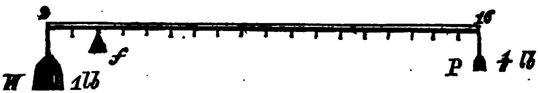
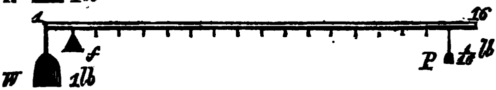


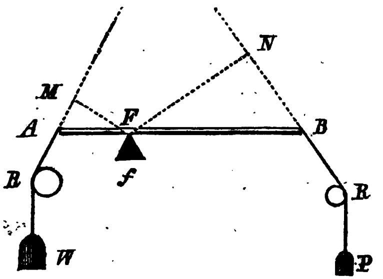
Fig. 50.



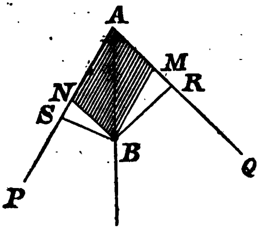
To prove this law by actual EXPERIMENT, take a lever (Fig. 47), resting upon the prop, *f*, in such a manner that the distance of the power to that of the weight from the fulcrum may be as 8 to 4, or as 2 to 1; then a power of $\frac{1}{2}$ lb. will be in equilibrium, or equal to the weight of 1 lb. The *moment* of the power is, in this case, $\frac{1}{2} \times 8 = 4$, and the *moment* of the weight $1 \times 4 = 4$; consequently, these moments are in equilibrium. Let the lever be now arranged as in Fig. 48, so that the distance of the power from the fulcrum is 16 inches, whilst the distance of the weight from the fulcrum is but 4 inches; then $\frac{1}{4}$ lb. power will be in equilibrium with the weight of 1 lb. Here the momentum of the power is $\frac{1}{4} \times 16 = 4$, and that of the weight $1 \times 4 = 4$; consequently, the moments are equal. The fulcrum placed as in Fig. 49, makes the momentum of $\frac{1}{8}$ lb. power, by the distance of 16 inches from the fulcrum, $\frac{1}{8} \times 16 = 2$, which, therefore, will be equal to the momentum of the weight, $1 \times 2 = 2$. If the fulcrum is still nearer the weight, as represented in Fig. 50, then $\frac{1}{16}$ lb., or 1 ounce, will balance 1 lb. weight, &c.

If the directions of the power and weight are not perpendicular to the arms of the lever, as we have supposed in the last ex-

Fig. 51.



amples, but act at oblique angles, as represented in Fig. 51, then, by continuing the directions RA, RB, and dropping upon them the perpendiculars FM, FN, from the fulcrum, these perpendiculars will mark the respective distances of the weight and power from the prop, with regard to which, the same reasoning applies as in our last examples.*



* To understand why this is so, let us at first consider a straight line, AB, supported at its lower end, B, in such a manner that it may move round that point, either to the right or left. Upon the point A (and in the same plane), let act two powers, P and Q, one urging the line AB in the direction AP, and the other, at the same time, urging it in the direction AQ. Let AN and AM represent these impulses; then it is easily perceived, that, in order to prevent the line AB from being moved in either direction, it is necessary that the force P should be to the force Q as the side AN is to AM, or, which is the same, as BM is to BN (BM being equal to AN, and BN to AM); for, in this case, the line AB itself is the diagonal resulting from the lateral forces AM and AN (see § 77). This diagonal being supported in B, no motion whatever can take place, and the line AB will remain in the state of rest. If, instead of the line AB, we imagine the whole parallelogram AMBN supported in B, then it will make no difference whether the two forces P and Q act upon the point A, or in M and N, provided their directions, AP and AQ, are not changed. Now, if you drop the perpendiculars BR, BS, to the directions AP, AQ, respectively, the two similar triangles, BMR and BMS, will have their two sides BR and BS in the same ratio as BM to BN; consequently, the parallelogram, AMBN, is still in equilibrium, when the two forces P and Q are in proportion to their distances, BR and BS, from the fulcrum, B; and the same will take place, if, instead of the parallelogram, ABMN, we have only the inflexible angle, MBN; or the lever, SBR, turning on the point B: hence the two forces P and

Fig. 52.

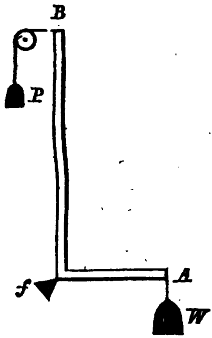
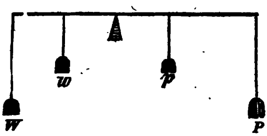


Fig. 52 represents a rectangular lever, where f is the fulcrum, and the two arms, Bf, fA, respectively, are the distances of the weight and power. When the power and weight are distributed as in this figure, a larger power is required to balance the weight, because the arm fA is shorter than Bf, and, to establish the equilibrium, it is again necessary that the power should be to the weight inversely as the distances fA and fB from the fulcrum.

§ 102. *When there are several powers, p,* P (Fig. 53), *and weights, w,* W, *operating upon the lever, then they will be in equilibrium when the sum of the moments of the weights is equal to the sum of the moments of the powers.* If some of those powers or weights are acting in opposite directions (see Fig. 54), then, instead of adding their moments, they are to be subtracted.

Fig. 53.



Let the two weights in Fig. 53 be 10 lbs. and 5 lbs., respectively, and let their distance be 4 and 2 feet from the fulcrum: then their moments would be $40 + 10 = 50$; and, in order that the powers P and p may be in equilibrium with these weights, their moments must also be equal to 50.

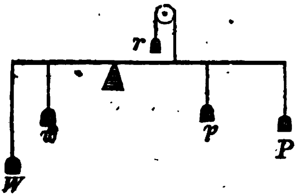
Q are in equilibrium if they are to each other inversely as their distances, BS, BR, from the fulcrum; which proportion may be expressed thus:—

$$P : Q :: BR : BS.$$

$$\text{Whence } Q \times BR = P \times BS.$$

(See Grund's Plane Geometry, Theory of Proportion.)

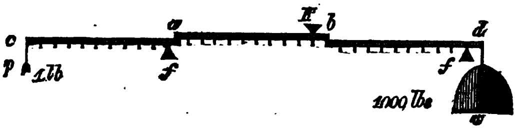
Fig. 54.



In Fig. 54, the two weights W and w are to be balanced by the three weights P, p, and r; but r, acting in a contrary direction, must be considered an additional weight; and, as such, its momentum must be either subtracted from the sum of the moments P and p, or it must be *added* to the sum of the moments of the weights W and w. Suppose W, w, and r, weigh 6, 3, and 2 lbs., respectively, and that their respective distances from the fulcrum are 10, 8, and 6 inches; then the sum of their momenta is $60 + 24 + 12 = 96$, which must be equal to the sum of the moments of the two powers P and p, in order that the lever shall be in equilibrium.

§ 103. *Compound Lever.* By combining several levers in such a manner that the weight of the first acts as a power on the second, and the weight of this lever again as a power upon a third, and so on, a compound lever is formed,

Fig. 55.



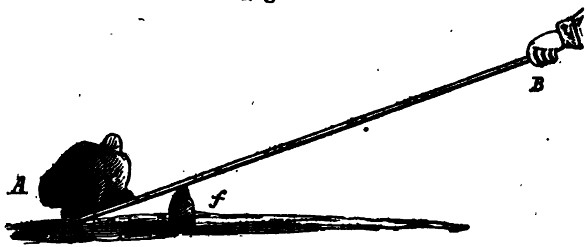
in which a very small power on the first lever may be in equilibrium with a very heavy weight on the last. Fig. 55 represents such a compound lever, composed of three simple levers, each of which is 10 inches in length, and has its fulcrum 10 inches removed from the power. The effect of this arrangement is easily calculated. Let the power of the first lever be 1 lb.; then, according to the law of § 101, it would be in equilibrium with a weight of 10 lbs., and therefore exercise a power equal to 10 lbs. upon the second lever. This new power is now in equilibrium with 10 times $10 = 100$ lbs. weight on the second lever; and this weight, acting as a power upon the third lever, is in equilibrium with 10×100, or weight of 1000 lbs. The advantage of such a system of levers consists not only in the immense

weight with which a small power may thus be in equilibrium, but also in the space which is saved.

In the above arrangement, three levers of 11 inches are employed, occupying, in all, but 33 inches in length. Had we wished to balance the same power by the same weight on a single lever, whose fulcrum is at the distance of 1 inch from the weight, we should have been obliged to employ a bar of 1001 inches in length, occupying an additional space of 968 inches.

Use of the Lever. The lever serves to raise heavy weights by small powers. There are infinite applications of the lever. Among these, it will suffice to mention but few. The crowbar

Fig. 56.



or handspike, AB, represented in Fig. 56, is a lever employed to lift a heavy mass, by placing the fulcrum (commonly a stone) near the weight, and applying the hand as a power in B A poker to raise fuel has for its fulcrum the bar of the grate on which it rests. Scissors, pincers, nippers, and shears, consist each of two levers, whose fulcrum is in the pivot. The brake of a pump, the oars of a boat, the rudder of a ship, chipping-knives, nut-crackers, wheel-barrows, &c., are all instances of levers. All weighing machines, balances and steelyards, of which we shall speak in the next Chapter, are founded upon the theory of the lever. Finally, the limbs of animals and men are levers, of which the socket of the bone is the fulcrum.

OF THE CENTRE OF GRAVITY.

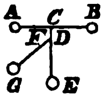
§ 104. The point in which an inflexible bar, or a lever (see Fig. 53, page 93), charged with several weights,

must be supported, in order that it shall neither move in one way or another, is called its *centre of gravity.* It may easily be found from the above law of the lever (§ 101, page 90).

§ 105. *The pressure which such a bar exercises upon the prop which supports it, is equal to the sum of all the weights with which it is charged.* Thus, if the sum of all the weights is 100 lbs., their pressure upon the prop is equal to that produced by a single weight of 100 lbs. If the sum of all the weights is 300 lbs., the pressure on the prop will be 300 lbs., and so on.

§ 106. *Every heavy body may be considered as an assemblage of small weights, held together by the attraction of cohesion, as by straight lines.* Let us, at first, consider two of these weights, A and B (see Figure 57) their centre of gravity will be somewhere between A and B, say in C. If with this we combine a new weight, E, then the centre of gravity will be somewhere in D (between C and E). In the same manner we may combine this new centre with a new weight, G, which would bring the centre of gravity somewhere in F; and it is easily perceived, that, by continuing to reason in this way, we shall be able to find a point in which the whole weight of the body, consisting of ever so many heavy points, A, B, E, G, &c., is concentrated, and which is therefore called the *centre of gravity.*

Fig. 57.



§ 107. A vertical line drawn through the centre of gravity is called the *direction of the body's weight,* or simply the *line of direction.* If this line is in any point supported or fixed, the body will remain motionless. Such a point may be found by trials, by balancing the body on a sharp point, or by suspending it: the direction of the cord, which is then one and the same with the direction of gravity, will always pass through the centre of gravity.

In a uniformly dense body, the *centre of gravity* is in the *centre,* that is, in that point of the body around which its mass is equally disposed. Thus, in a sphere of uniform density, the centre of

Fig. 58.

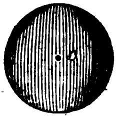


Fig. 59.

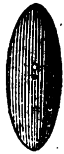
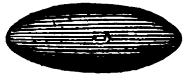


Fig. 60.



gravity is in the centre, C (Fig. 58). In a prolate spheroid (Fig. 59), and in an oblate spheroid (Fig. 60), it is likewise in the centre.

Fig. 61.

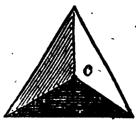


Fig. 62.

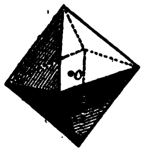
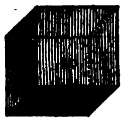


Fig. 63.



In the regular solids, the tetrahedron (Fig. 61), octahedron (Fig. 62), and cube (Fig. 63), &c., it is likewise in the middle; because each of these solids may be inscribed in a sphere.

Fig. 64.

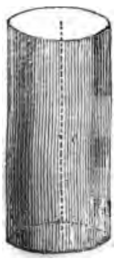
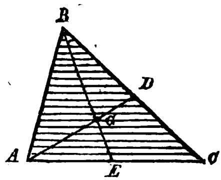


Fig. 65.

Fig. 66.

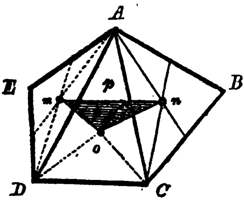


In a cylinder (Fig. 64), or prism (Fig. 65), of uniform density, the centre of gravity is in the middle, C, of the axis; and in a similar manner may the centre of gravity of other regular solids be determined. If the body consists of a flat plate of uniform density, and is bounded by straight lines, its centre of gravity is yet easily found. Let us begin with the simplest rectilinear figure, which is a triangle, ABC (Fig. 66). By dividing the basis AC into two equal parts, and drawing the line BE, the centre of gravity

will evidently be in this line; because, by drawing parallel lines to the basis BE, we may consider the body as an assemblage of levers, which, by the line BE, are all divided in the centre. For the same reason, by bisecting the line BC by the line AD, the centre of gravity of the triangle will also lie in this line; because, by imagining parallels drawn to the line BC, we may consider the body as composed of an assemblage of levers which are all intersected in the centre by the line AD; and as the centre of gravity of the triangle ABC must be in both the lines BE, AD, it must, evidently, be in their intersection, G. This may be proved by experiments with a piece of thin card. The triangle being divided by the lines BE, AD, as in the last figure, and the point G placed on a sharp point, the whole will be balanced.

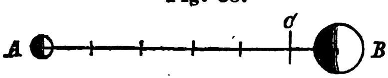
Suppose, now, it were required to find the centre of gravity of a plate, ABCDE (Fig. 67): then, by dividing the whole figure into triangles, as is done in the figure, and by finding the centre of gravity of each triangle in the manner we have just explained, we obtain three points, *m*, *n*, *o*, in which the whole masses of the triangles ABC, ACD, ABD, are active. Considering, in the first place, the two masses *m* and *n*, we can suppose them to be connected by a straight line, *mn*, of which the centre of gravity may be found by the law of the lever. Let *p* be that point. By connecting it with the point *o*, we can consider *po* as a lever, where *p* represents the two masses *m* and *n*, and *o* the mass of the triangle ADC; and the centre of gravity of this lever will be that of the whole plate, ABCDE.

Fig. 67.



The centre of gravity of an inflexible bar with unequal weights upon it, may be found by the law of the lever, as in the following example: Suppose AB is such a bar: let the mass of A be 1 lb. and that of B 5 lbs.; then, by dividing the whole distance from A to B into six equal parts, the centre of gravity will be in C; because the distance 1 by the weight 5 is equal to the distance 5 by the weight 1.

Fig. 68.



If the lever AB is, in the point C, connected with another weight, then the joint weight of the two masses A and B will be active in C; and it will be the same as if there were but one

lever, whose centre of gravity may be found as in the first example.

It is not always necessary that the centre of gravity should be *within* the body. In a ring, for example, the centre of gravity is in the centre, C (see the figure); and if this point is connected by thin thread with the substance of the ring, the whole may be balanced on that point. In all these examples, we have supposed the masses of the bodies throughout equally distributed. If this is not the case, then the centre of gravity cannot be found by mathematical reasoning of so simple a nature, but requires the aid of principles of analysis which cannot very well be introduced in a treatise of this nature. But in all such cases, the centre of gravity may be easily found by experiments. Let ABCD (Fig. 70) represent an irregular body; suspending it in C, and marking the direction of the plumbline when the body is at rest, we obtain the direction in which its centre of gravity must necessarily lie; suspending it afterwards from another point, B (Fig. 71), and again marking the direction of the plumbline, we shall have two straight lines drawn, the common intersection, *m*, of which will indicate the point where the centre of gravity must be situated; and, by supporting that point, the whole body will be at rest.

Fig. 69.

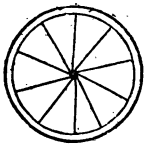


Fig. 70.

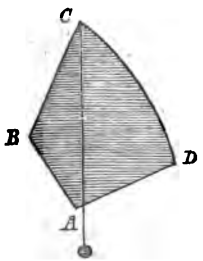
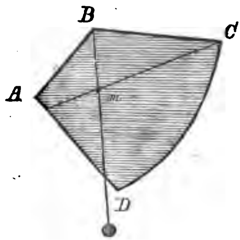


Fig. 71.



§ 108. When a body is placed upon a basis, its stability depends upon the relative position of the line of direction (§ 107). If the line of direction falls within that basis, it will stand the firmer, the nearer that line falls to the centre, and will be liable to turn over when it falls near the edge of the basis: finally, when the direction of gravity falls without the basis, the body must turn over that edge which is nearest the line of direction.

Thus a right pyramid stands safest, because the line of direction, AC (Fig. 72), falls in the centre of its basis, EFG; but a body of the form represented in Fig. 73 will not stand so safe. Let the centre of gravity of the pyramid be in C: then, in order to turn it round the point E, it is necessary that the point C should describe the arc CD; but, as long as the line of direction is supported, the body cannot fall: hence, in order to turn the pyramid, it is necessary that the point C should be moved beyond the arc C*m*; because, when in the point *m*, the centre of gravity is yet supported. In Fig. 73, the point *m*, beyond which the centre of gravity must not be moved, is in the body itself: hence a slight push may overset it.

Fig. 72.

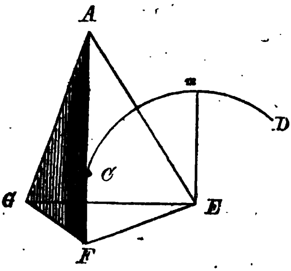
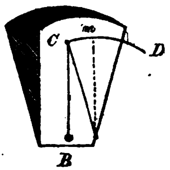


Fig. 73.



A ball cannot rest upon a plane unless its position is perfectly horizontal, because only then the line of direction, CD, falls upon the point D, which is supported by the plane. But a spherical body cannot rest on an inclined plane (Fig. 75), because the line of direction is never supported, and it will therefore be obliged to descend the plane, its centres moving all the time in a line, AB, parallel to the plane. This motion has already been considered in § 89, page 81.

Fig. 74.

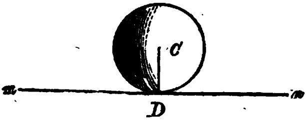
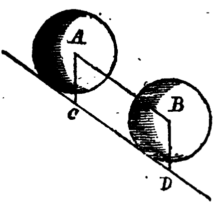


Fig. 75.



Phenomena explained by the Theory of the Centre of Gravity. What has been said about the centre of gravity will serve to explain a number of phenomena. A large table cannot stand firm on a single leg, unless that leg terminates in a tripod. The feats of rope-dancers are greatly facilitated by holding a heavy pole; because the centre of gravity of the dancer and pole together is then brought near the centre of the pole, which the dancer holds in his hand. When a man walks, he throws his body a little forward, in order to make the centre of gravity fall in the direction of his toes, and assist thereby the muscular action, which propels the body in the same direction. A quadruped never raises two feet on the same side, because the centre of gravity would then cease to be supported. When a porter carries a load on his back, he throws his body forward, to bring the centre of gravity (of his body and the load) within the basis of his feet. If he carries the load on his head, he will go erect; and when carrying it in his arms, he leans backwards. For the same reason does a man incline forward when ascending a hill, and backward in descending it. When a person wishes to rise from a chair which has no back, it cannot be done without inclining the body forward, so as to bring the centre of gravity in the direction of the feet; or drawing back the feet, so as to bring them under the centre of gravity.

I. LAWS OF PERCUSSION.

§ 109. *Central and Eccentric Percussion.* When a moving body meets another on its way, it will strike that body with a force proportional to its moment. If the line in which the centre of the striking body moves passes also through the centre of the body on which it strikes, then the percussion or stroke is called *central;* otherwise it is termed *eccentric.*

§ 110. Among the numerous cases of percussion that can take place, but few can be made the subjects of elementary investigation. Among these we will mention the following three:—*Percussion of two unelastic bodies; percussion of an elastic body with an unelastic body; and, finally, percussion of two elastic bodies.*

1. *Laws of Percussion of Unelastic Bodies.*

§ 111. When two unelastic bodies strike against each other, three cases can occur:—*the two bodies may move*

against each other, and have equal moments; or they may move against each other, and have unequal moments; or they may move in the same direction, and have unequal velocities, so that the one which moves behind must overtake the other.

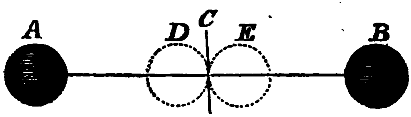
1. In the first of these cases, *the motions of both bodies will be entirely destroyed.*

2. In the second case, *the motion of the body whose moment was less before the stroke, will not only be destroyed, but it will be compelled to move in the opposite direction, following the impulse of the greater moment.* Both bodies may then be considered as one mass, moving with a velocity corresponding to the difference between the original motions.

3. In the third case, *the striking body loses as much of its moment as the other gains;* both bodies will continue to move in the same direction.

To illustrate these laws, let us, in the first place, suppose that the two balls, A, B (Fig. 76), have equal masses and velocities, but

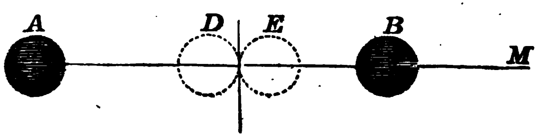
Fig. 76.



opposite directions. Then it is easily perceived, that, at the stroke in C, both motions will be destroyed, and the two bodies will remain in the respective positions D and E.

To illustrate the second case, let us suppose the two bodies A and B (see Fig. 77) are again moving against each other; but A

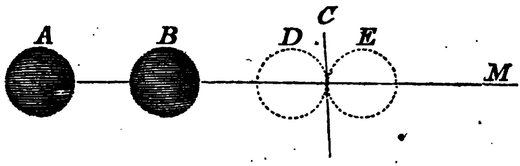
Fig. 77.



with the velocity 6, and B with the velocity 4. Then B will lose its whole velocity by the stroke, A only 4; and the remainder, 2, will be divided between A and B. Both bodies will now move, with the velocity 1, in the direction from D to M.

The third case may be exemplified by two bodies, A and B, moving in the same direction. Let A's velocity be 6, and B's 4

Fig. 78.



(the masses being equal); then A (Fig. 78), will overtake B, and, during the stroke, communicate to it as much motion as will equalize their velocities. Both bodies will continue to move in the same direction with the velocity 5; A will have lost 1, and B received an addition of 1 to its velocity.

2. *Laws of Percussion of Elastic Bodies.*

§ 112. *When the two bodies are both perfectly elastic, then the reaction of each of them upon the other must be equal to the loss or gain which it receives from the other.* Thus, if the one gives the other the impulse 5, it receives, by the elasticity of the other, the same impulse, 5, back again, in the opposite direction.

§ 113. The law just named will enable us to determine the three principal cases that may occur in the percussion of elastic bodies.

1. When the two bodies (whose masses we will again suppose to be equal) move against each other;
2. When the one stands still, and the other strikes upon it; and
3. When both move in the same direction, but the one which moves behind with a greater velocity, so as to overtake the other.

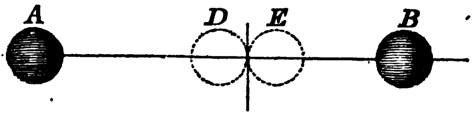
In the first case, *they will exchange velocities, and move in the opposite directions to those they had before the stroke.*

In the second case, *the body which stood still will receive the velocity of the striking body, and the striking body will remain in the place of the other.*

In the third case, *they will again exchange velocities, but continue to move in the same direction.*

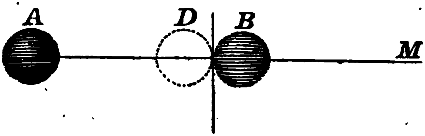
If the two bodies, A and B, move against each other, A with the velocity 5, and B with the velocity 3, then, after the stroke, A

Fig. 79.



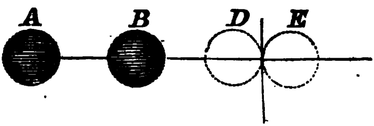
will return with the velocity 3, and B with the velocity 5. During the stroke, A lost 3 of its velocity, in the direction from A to B (because 3 is the velocity of B); but by the reaction of the elastic body B, it receives the whole impulse, 5, back again, in the direction from D to A; which not only cancels the velocity, 2, remaining after the stroke, but impels it backwards with the velocity 3. In the same manner it may be shown that B must return from A to B with the velocity 5.

Fig. 80.



If B stands still, and A strikes upon it with a certain velocity, say 4, then the body B will be impelled from B to M with the velocity, 4, which A had before the stroke, and A will receive B's velocity, which was 0; that is, it will remain in D. This is frequently seen at a billiard table, when the balls are perfectly elastic, and is only a modification of the first case.

Fig. 81.



Finally, let both move in the same direction, A with the velocity 5, and B with the velocity 3. After the stroke, their velocities will be exchanged; A will move with the velocity 3, and B with the velocity 5. This may be explained in the following manner: —During the stroke, A and B's velocities become equalized. A's surplus of velocity being 2, it will give 1 to B. This, and an additional 1, which A loses by the reaction of B, reduce its velocity to 3; while the velocity of B, by the gain of 1, and an additional 1, in consequence of the reaction of A, will have increased to 5. The directions will remain the same as before the stroke.

§ 114. *When an elastic body impinges against an unelastic, firm plane, or an unelastic body against an elastic, firm plane, then it will rebound from it in such a way that the angle of incidence is equal to the angle of reflection.* Thus, if the body A strikes the plane MN in the direction AB, then it will rebound in the direction BC, making the angle *a* equal to the angle *b*.

Fig. 82.

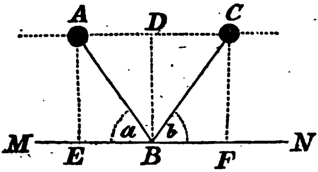
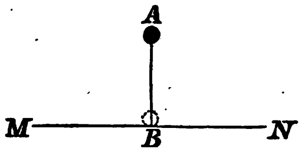


Fig. 83.

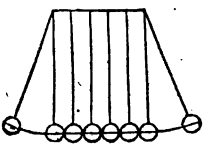


If the angle of incidence is a right angle, it will rebound in the direction BA (Fig. 83) with the same velocity as it struck the plane MN.

The force AB (see Fig. 82) may be decomposed into the two lateral forces AD and AE, of which the former is parallel to the plane MN, and the latter perpendicular to it. When the body has arrived in B, it may again be considered as receiving two impulses, one to move along the plane BN, with a force equal to BF, and another to rebound at right angles, with the velocity BD. The diagonal force BC, therefore, must make the same angle with the plane MN which AB made with it. This may be illustrated by an experiment on a billiard table.

§ 115. When several elastic balls, of equal magnitude, are suspended in such a way that their centres lie all in the same straight line (see the figure), then, when the first is raised from its position, and let fall again, so as to strike upon the second, the motion will transmit itself through all the balls, which will remain in the state of rest, and only the last will bound off, with a velocity equal to that with which the first ball struck upon them.

Fig. 84.



The explanation of this phenomenon follows from the 2d case, page 103.

VIBRATING MOTION.—ACOUSTICS.

§ 116. *Vibrations—Sound.* When a body is put in a vibrating motion, and the vibrations are going on with a certain velocity, they are productive of sound; and the reverse is also observed, namely, that every body which shall produce sound must first be put in a vibrating motion.

These vibrations may be noticed on a sounding-bell, by suspending a little ball of cork or sealing-wax, so that it touches the bell exteriorly. As long as the bell is sounding, the ball will be tossed to and fro like a pendulum. Dust or quicksand will be thrown off from a sounding body. Small pieces of paper, hanging on a violin string, are thrown off when the bow is drawn. When the sound is very powerful, such as is produced by the ringing of several bells, or by the firing of cannon, then these vibrations shake even walls and houses; which proves that they communicate themselves also to other bodies.

§ 117. *Propagation of Sound—Hearing.* If these vibrations are any ways propagated, so as to reach our ear, we *hear* the sound, and denote by the word 'hearing' the sensation which the sounding body produces in our ear.

The different modifications of sound, its highness or graveness, its power or feebleness, the variety of human and animal voices, the different sounds of musical instruments, produce each a distinct sensation in our ear, incapable of being described. The description of the human ear, &c. belongs properly to physiology.*

§ 118. *Medium of Propagation.* The medium through which sound is commonly propagated is the atmosphere. All other bodies, however, whether solid or liquid, are capable of doing the same, in a greater or less degree.

This may be shown by experiments. The ticking of a watch is heard at a distance of several feet, when the watch is held at one end of a board or pole, and the ear at the other. The sound from a diving-bell is heard through the water, &c.

§ 119. *Vibrations produced in the Atmosphere.* The vibrations which a sounding body produces in the surround-

* Those who wish to be informed about it, will find it in Blumenbach's Physiology, translated by Charles Caldwell. Phil. 1795.

ing atmosphere resemble the undulations of waves, and consist in expansions and contractions, *without communicating to the atmosphere a progressive motion.*

This is the reason why a sounding body produces no wind, does not blow out a candle, &c. It explains, also, why we can hear several musical sounds at the same time; because the vibrations produced in the atmosphere may intersect each other in various directions, without disturbing each other's motion, like the undulations produced on the surface of water by throwing stones into it.

§ 120. *Requisites of a Sonorous Body.* In order that a body shall be capable of producing sound, it is necessary that it should be elastic; for a body without elasticity cannot be put in a vibrating motion, and consequently will produce no sound (§ 116, page 106.) The capacity of a body for sound increases with its elasticity.

§ 121. When a sonorous body vibrates, there are always certain points or lines in its surface, which remain in the state of rest. In the same manner does a vibrating chord frequently divide itself into aliquot parts. (This discovery was first made by Dr. Chladni, of Wittenberg.*)

The points and lines which remain in the state of rest, while the remainder of the sonorous body is vibrating, may be exhibited to the scholars by one of Chladni's simplest experiments:—Take a circular or square pane of common window-glass, cover it thinly with pulverized alabaster, and hold it in such a manner between your thumb and finger, that only the ends of them actually touch it. Then draw a violin bow across its edge, until it produces a clear sound. The moment that this takes place, the powdered alabaster is partly thrown off the pane, but remains in certain fixed places, forming, in most cases, a regular symmetrical figure. If the bow be afterwards drawn in a different place, this figure will immediately change: the higher the tone is which is thus produced, the more complicated is the figure; the lowest sounds produce the simplest figures.—Another experiment, which is still more simple, is this. Take a tumbler half filled with water, and draw a violin bow or a wet finger across its edge, until it produces a clear sound. The surface of the water in the tumbler will, at the same moment, be thrown into an undulating motion; but it will be easy to perceive that the undulations proceed only from certain regular places, while there are others in which the water remains entirely in the state of rest.

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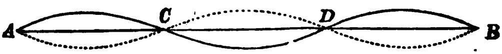
* See Chladni's Acoustics. Leipzig, 1802.

§ 122. If the places which are exempt from the vibrations of a sonorous body, are touched with the finger, the sound is not only not prevented, but not even modified; while, on the contrary, all sound ceases, or is, at least, weakened and changed, when one of the vibrating parts is brought in contact with some other body.

When a stretched chord swings, it generally divides itself into aliquot parts, and swings after the manner represented in Fig. 85.

Fig. 85.



If in the points C and D, which remain at rest, small pieces of paper be placed, they will not be thrown off when the chord swings, or when a violin bow is drawn across it. Nor will the sound cease when those points are touched with the finger. But if any other point be touched, the sound will either cease, or the sound of the vibrating body will be considerably modified.

This is the reason why the tongue of a bell must immediately recede from it, after striking; why a fractured bell does not produce a clear sound, &c.

§ 123. *Influence of the Length, Thickness, and Tension of the Chord.* The height or depth (acuteness or gravity) of sound produced by chords depends upon the length of the chords, their densities and their thicknesses. The theory of vibrating chords may be reduced to that of the oscillations of a pendulum; and it may be proved mathematically, that *the number of vibrations, and consequently, also, the acuteness of sound, are in direct proportion to the square roots of the tensions, and in the inverse ratio of the lengths and thicknesses of the chords.**

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* If L, l, respectively, stand for the lengths of two chords; P, p, for their tensions, or the degree of force with which they are stretched; T, t, for their thicknesses; and N, n, for the number of vibrations each makes in the same time; then we shall have the following proportions:—

$$N : n = l : L.$$
$$N : n = t : T.$$
$$N : n = \sqrt{P} : \sqrt{p}.$$

§ 124. If the thicknesses and densities are the same, then the number of vibrations is in the inverse ratio of the length; that is, *the shorter chord will give the higher tone.*

This we know from experience; and it may be proved by a variety of experiments.

§ 125. *Unison.* When two chords are stretched to such a degree, and have such lengths and thicknesses, that they make the same number of vibrations in the same time, then *they will also give the same tone*, and are therefore said to be in unison (*unisono.*) If the chords are made of different substances, then there will be a *specific* difference in the tone, but none with regard to height or depth.

Whenever a chord is struck, an exercised ear will, besides the principal tone, hear several others sounding with it. This phenomenon probably originates in the chord being more stretched at the two ends than in the middle. A tone is the clearer the fewer of these sounds are heard. This consideration is important for the perfection of musical instruments. On these tones depend principally the sweet sound of the Æolian harp. This instrument consists of a simple box of wood, two or three feet long, upon which five or six strings are stretched, as upon a guitar. When *they are tuned in unison*, and the instrument is exposed to a gentle draft or breeze, some of the strings vibrate entire, while the others divide themselves into equal parts. The various notes thus produced are generally in perfect harmony, and the gradual succession of accords, which at regular intervals strike the ear, and mingle with each other in sweet, melodious strains, is not to be surpassed, in pathos or softness, by the most skilful performer on any instrument. But to enjoy all the beauty of the Æolian harp, the ear must be well cultivated by music. Any other stringed instrument, tuned in unison, will, in a degree, produce the same phenomena.

§ 126. *Octave—Quint—Quart—Tetrachord.* When a chord, *c*, makes, in the same time, twice as many vibrations as another chord, C, then it is called *the next higher octave of* C; when a chord, G, makes three vibrations, while C makes two, then G is the *quint* of C; and when *c* makes four vibrations to G's three, then *c* is the *quart* of G.

Thus the ratio of the first (which is called the *fundamental* tone, C) to its next higher octave, is as . . . 1 to 2
That of the quint, G, to the fundamental tone C, as . 3 to 2
And that of the quint, G, to its quart, *c*, which is at the same time the octave of C, as . . . . 3 to 4

These three notes form the simplest scale, and are supposed by some to have formed the tetrachord of Hermes.

§ 127. *Gamut—Diatonic Scale.* There are seven principal tones or notes in an octave from C to *c*: these are

C, D, E, F, G, A, B, *c*;

of which C is called the *fundamental* tone, D the *second*, E the *tierce*, F the *quart*, G the *quint*, A the *sèxt*, and B the *septima*, of the fundamental tone, C. These seven tones are what, in music, is called the *gamut*, or *diatonic scale.*

§ 128. *Numerical Value of Notes.* By the *numerical value of a tone or note*, we mean the number of vibrations which it makes, while the fundamental tone makes 1 vibration. Thus, if the fundamental tone is 1, the value of the next higher octave is 2; that of the next lower octave, $\frac{1}{2}$; that of the next higher quint, $\frac{3}{2}$; that of the next lower quint, $\frac{2}{3}$; that of the next higher quart, $\frac{4}{3}$; and that of the next lower quart, $\frac{3}{4}$.

The numerical values of the seven tones or notes of the diatonic scale, derived from these, are nearly as follow:—

C,	D,	E,	F,	G,	A,	B,	c.
1,	$\frac{9}{8}$,	$\frac{81}{64}$,	$\frac{4}{3}$,	$\frac{3}{2}$,	$\frac{27}{16}$,	$\frac{15}{8}$,	2

§ 129. *Musical Interval.* The ratio of one tone to another—for instance, that of the fundamental tone to the second, which is 1 to $\frac{9}{8}$—is, in music, termed the *interval* between C and D.

§ 130. *Inequalities of Musical Intervals.* The successive intervals between the seven tones of the diatonic scale are not equal to one another. The ratio of the fundamental tone C to D, for instance, is not the same as that of E to F, or *a* to B. Thus, although E is the tierce of C, F is not the tierce of D, G not the tierce of E, &c.

§ 131. *Chromatic Scale.* On this account, the diatonic scale does not satisfy the demands of modern music; and in its stead is used the *chromatic scale*, which has five additional semitones, inserted between C and D, D and E, F and G, G and A, A and B.

The numerical values of these notes are as follow:—

C,	C sharp,	D,	D sharp,	E,	F,
1,	$\frac{243}{256}$,	$\frac{8}{9}$,	$\frac{27}{32}$,	$\frac{4}{5}$,	$\frac{3}{4}$;

or, expressed in decimals,

1.0000,	0.9492,	0.8888,	0.8437,	0.8000,	0.7500,
F sharp,	G,	G sharp,	A,	A sharp,	B,
$\frac{32}{45}$,	$\frac{2}{3}$,	$\frac{81}{128}$,	$\frac{161}{270}$,	$\frac{9}{16}$,	$\frac{8}{15}$,
0.7111,	0.6666,	0.6328,	0.5963,	0.5625,	0.5333,
c.					
$\frac{1}{2}$.					
0.5000.					

Here the numerical values of A and E differ a little from those given in the diatonic or natural scale. This impurity, however, was necessary, in order to make the intervals, as nearly as possible, equal to one another. It is particularly indispensable with instruments which have but twelve notes in an octave. No musical instrument, namely, can give every interval as clear and distinct as the human voice. The most perfect of all, and that which approaches nearest to it, in purity and variety of tone, is the organ.

There are yet other scales, used by composers of music: in Germany, for instance, the equally-tempered scale (Gleichschwebende Temperatur.) The chromatic scale, however, is generally preferred.

§ 132. *Harmony—Discord.* When several notes are sounded together, they either produce an agreeable or a disagreeable sensation in our ears. In the first case, they are said to form *harmony*, or *concord;* and in the second case, *discord*, or *dissonance.* To give an example: the fundamental tone and the quint always produce concord; the second and septima always discord; the fundamental tone, C, the tierce, G, the quint, A, and the octave, *c*, give a perfect accord.

§ 133. *Melody.* Melody consists in a succession of simple and suitable notes, following each other in regular intervals of time. In the choice and arrangement of these notes, and in the regulation of the time in which they are to follow each other, consists the difficulty, and, at the same time, the beauty of musical compositions.

The reason why the striking of several notes at the same time

is in some cases agreeable and in others disagreeable to the ear, cannot be satisfactorily explained, and forms a proper subject for physiology.

Dissonances in a melody frequently serve to enhance the beauty of the following harmony. Mozart's compositions, which may serve as models to all ages, afford striking instances of such artificial dissonances.

§ 134. Very high or very low tones are no longer audible. Five or six octaves probably comprise the whole system of notes fit for music.

The deepest audible tone is produced by an open organ pipe of thirty-two feet length.

§ 135. *Remarkable Discord on the Violin.* Very remarkable is the sound produced on a common violin-string, by drawing the bow under a very acute angle. The chord, instead of making transversal vibrations, will then vibrate longitudinally (lengthwise). The sound thus produced is exceedingly disagreeable to the ear, and is frequently from three to five octaves higher than the natural tone produced by the chord's vibrating transversely.

The height or acuteness of the sound thus produced does not depend upon the thickness or tension of the chord, but solely upon its length. The phenomenon just described explains, in some degree, why the discords on the violin are more disagreeable than those on any other instrument.

§ 136. *Propagation—Velocity of Sound.* The velocity with which the vibrations of a sounding body are propagated through the air, is from 1036 to 1040 Parisian feet, or from about 1105 to 1110 feet English measure,* in a second of time.

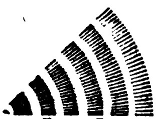
Different densities in the atmosphere—dampness, heat, winds, &c.—modify the propagation of sound through the air, which is the reason why its velocity varies from 1105 to 1110 feet in a second. A loud sound can be heard farther than a low one, because greater vibrations of the sonorous body communicate more motion to a greater number of particles of air. The propagation

* See Tobias Mayer's Practical Geometry, Vol. I. page 51. (Practische Geometrie von Tob. Mayer. Iter Theil, Seite 51.)
Chladni's Acoustics. Leipzig, 1802. (Since translated into French, by the author, upon a demand of the late emperor Napoleon.)
Perolle, in Gilbert's Annals of Nat. Phil. Vol. II.
Biot, Traité de Physique expérimental, Tom. II.

of sound through the medium of other bodies has not, as yet, been sufficiently investigated. Chladni's experiments, however, show that solid bodies propagate the sound better and quicker than air. Biot and Hasenfratz found the same by experiments.

§ 137. *Rays of Sound.* The vibrations which every sonorous point causes in the surrounding atmosphere, may be considered as rays of sound, emanating, in all directions, from the sounding body (see Fig. 86), and making regular pulsations in *a*, *b*, *c*, *d*, *e*, &c., where the air is compressed.

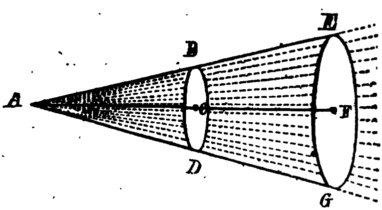
Fig. 86.



Since these rays are nearer together, in the neighborhood of the sonorous body, than farther from it, it is evident that the sound will be heard better near it than at a distance; and it may be proved mathematically, *that the intensity of sound decreases in the inverse ratio of the square of the distance.* Thus, at two rods' distance, the sound is four times weaker than at one rod's distance; at three rods' distance, it is nine times weaker, &c.

Until now, but few *experiments* have been made on this subject; yet the truth of the mathematical theory, which is founded on the known property of the sections made parallel to the basis of a cone, cannot be doubted.*

Fig. 87.



Let A be a sonorous point, from which emanate rays of sound in a conical form, as represented in the figure. Suppose these cones intersected by the two planes, BD, EG, which, as we know from geometry, will be circles. The two similar triangles, ABC, AEF, will give the proportion

$$AC : AF :: BC : EF;$$

whence

$$AC^2 : AF^2 :: BC^2 : EF^2;$$

* See Grund's Solid Geometry, Sect. III. Of Cones, 2d Consequence to Query II.

but the circles BD, EG, being in proportion to the squares of their radii, give the proportion

$$BC^2 : EF^2 :: \text{circle BD} : \text{circle EG};$$

hence $$AC^2 : AF^2 :: \text{circle BD} : \text{circle EG};$$

which was to be proved.

§ 138. *Reflection of Sound—Echo.* We know from experience, that, when a ray of sound strikes on a firm plane, it is *reflected from it*, according to the law of percussion of elastic bodies (see § 114, page 105); and the angle of incidence is equal to the angle of reflection.

Only the last pulsation—that is, only the few particles of air, which, in their vibration, strike the plane—are really reflected; but these immediately create new pulsations in the air, and form what is called the *ray of reflection.* This explains the phenomena of the echo, the operation of the acoustic tube (which is so constructed that the sound which strikes its inner sides is reflected in parallel rays), the use of the speaking trumpet, the whispering gallery, &c.

Fig. 88.

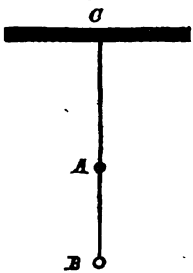
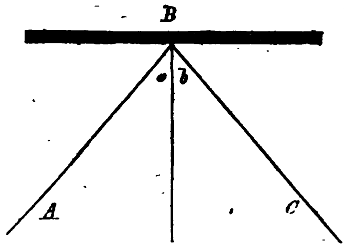


Fig. 89.

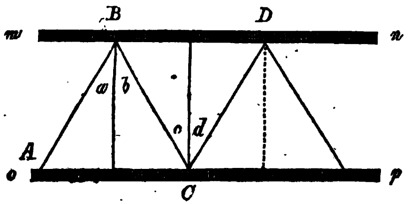


When a ray of sound, AC, (Fig. 88), meets a firm plane surface of sufficient magnitude, at right angles, it will, according to the law explained § 114, page 105, be reflected in the same direction; hence an ear, placed in the direction CA, say in B, will hear this reflected sound, which is known by the name of *echo.*

If the ray of sound strike the surface at an oblique angle, as represented in Fig. 89, then the ray, being reflected in such a manner that the angle of incidence, *a*, is equal to the angle of reflection, *b*, the ear, placed in the direction BC of the reflected ray, will hear the echo.

Sometimes several echoes are heard. This is the case when the sound is reflected from several surfaces, at unequal distances from the sounding body, the sound being, in this case, reflected sooner from the one than from the other; or when the sound emanates from a point situated between two parallel planes, from which it is mutually reflected.

Fig. 90.



Let AB (Fig. 90.) be a ray of sound striking one of the two parallel planes, *mn*, *op*; the angle of incidence, *a*, being equal to the angle of reflection, *b*, the sound will be reflected in the direction BC; but meeting in C the plane *op*, it is again reflected, according to the same law, in the direction CD; and so on. This reflection of sound is similar to that of light produced by two parallel plane mirrors, and continues until the sound is no longer audible, if the planes are sufficiently far continued.

Fig. 91.

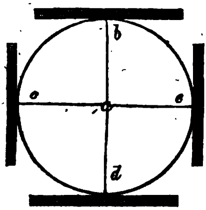
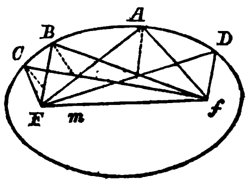


Fig. 92.

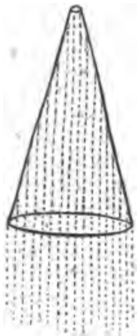


In a circular hall, every sound emanating from *a* (Fig. 91) will be reflected to it, as the centre of the circle. Thus the ray *ab* will be reflected back to *a*, the sound *ac* to *a*, and so of the rest. A very low sound, therefore, will, by the reflection from the wall, be audible in the centre.

If the shape of the hall be elliptical, as represented in Fig. 92, then every sound emanating from the point F will be reflected to the other focus, *f*, because it is the property of an ellipse to reflect straight lines from one focus into the other, making the angles of incidence equal to the angles of reflection. In such a hall, or building, a person standing in F will hear distinctly

every whisper proceeding from a person in *f*, whilst, to a person in *m*, much nearer the point F, the sound would scarcely be audible. Such a building is called a *whispering* gallery.

Fig. 93.



When the voice is thrown into a speaking trumpet (a section of which is represented in Fig. 93), the sound is reflected from the sides in parallel rays, and, being thereby prevented from spreading equally in all directions, is by this means carried farther than under ordinary circumstances, and is, at the same time, much louder than when uttered in the usual manner.

§ 139. *Wind Instruments.* When air is blown into flutes, trumpets, horns, or other wind instruments, it first vibrates longitudinally (lengthwise); but the sound thereby produced is modified by the different reflections from the sides of the instrument. By the opening or closing of the holes or keys, the length of the vibrating column of air is either extended or diminished, and by that means the different notes are obtained.

The reason why the sound is not prevented, by touching these instruments with the hand, is because it is not the substance of these instruments,—for instance, in trumpets, not the brass of which they are made,—but the column of air which is vibrating in it, which produces the sound; and these vibrations are not checked by touching the instrument outside. It is quite the reverse with chords or bells, which, by their own elasticity, are productive of sound. Bassoons and flutes must be made of wood, and not of metal; because, metallic substances being more elastic, the vibrations of the air would communicate themselves to the instrument, and thereby destroy the purity of its tone. For the same reason are very elastic metals, such as silver, brass, &c., unfit for the building of organs. Metallic speaking trumpets convey the articulated voice less distinctly (although farther) than those made of wood, or even pasteboard.

Remark. The description of the human speaking organs be-

longs to physiology, and may be given by the teacher. (See Caldwell's translation of Blumenbach's Physiology, Vol. I. Sect. XII. Of Voice and Speech.)

OBSTACLES OR HINDRANCES OF MOTION.

§ 140. *Hindrances of Motion.—No body has a perfectly smooth and even surface, even if it appear so to our senses,* because all bodies have pores or interstices. (§ 8, page 16.) Thus, when two bodies, ever so well polished, move upon one another, the little prominences and cavities caused by their pores, catch into each other, and thereby resist or retard their motion. This resistance, which is commonly termed *friction*, is one of the greatest hindrances of motion.

§ 141. *Laws of Friction.* The laws of friction cannot very well be fixed, because we have no precise measure of it. Nevertheless, we are enabled by experience to lay down the following principles:—

1. The velocity of the body has but little influence on its friction.

When a body moves swiftly, it will, in less time, meet with more protuberances and cavities, but, at the same time, have more force to glide over or overcome them.

2. If the pressure of the mass of a body is throughout the same, then the friction does not increase with the magnitude of its surface.

When a greater surface is presented, more particles are rubbed against each other; but the pressure upon any particular part of the larger surface is smaller than when the same pressure is exercised upon a smaller surface.

3. The more uneven a surface is, the greater is the friction, supposing every thing else to remain the same.

Very even and polished surfaces *increase* friction, because polishing favors their mutual attraction, by allowing them to touch each other in more points. (See § 34, page 35.)

4. The amount of friction is seldom more than one third of the pressure.

Sometimes it is only one fourth, one fifth, one tenth, and even a less part of the pressure of the bodies which are rubbed against each other.

5. The friction of woods and metals is greatest upon woods and metals of the same kind. Thus the friction of wood on wood is greater than that of wood on brass; and the friction of brass on brass greater than that of brass on steel, or on wood.

6. The friction of wood is less when moved lengthwise (parallel to its fibres) than when moved transversal (against the grain).

7. The friction of metals is increased by heat, that of wood by dampness.*

§ 142. When a heavy body is placed upon a horizontal plane, which supports its whole weight, then the least impulse parallel to the plane ought to set it in motion. Nevertheless, the friction on its surface presents considerable obstacles to the smallest change of its place. It is friction, also, which prevents the falling of a body on a moderately inclined plane; which enables us to climb up mountains, ascend or descend on inclined planes, &c.

A cask may be moved more easily than a box; because, by the rolling of a cask the friction is overcome in a manner similar to the pulley.

§ 143. *Means of avoiding Friction.* Since friction retards motion, it must be avoided, as much as possible, in machinery. This is effected in three ways:—

1. By bringing only such bodies in contact with each other, whose friction, we know from experience, is comparatively small.

2. By diminishing the points of contact.

3. By overspreading their surfaces with oil, tar, soap, fat, or any other substance which we know diminishes friction.

§ 144. *Resistance of the Atmosphere.* Another obstacle of motion is the resistance of the atmosphere. *The greater*

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* Tob. Mayer, Nat. Phil. page 160.
Coulombe, sur la Théorie des Machines simples, en ayant egard au Frottement. 1781.

the velocity of the body, and the surface which is presented to the air, the more particles of air will it have to remove on its way; the greater, therefore, will be the resistance of the atmosphere.

§ 145. *Laws of Resistance, &c.* The resistance of the atmosphere increases as the square of the velocity of the moving body.

For when a body moves with double the velocity, it has to remove *twice* as many particles of air, with double the speed; the resistance of the atmosphere is therefore twice $2 = 4$. If moving with 3 times the velocity, it will have to remove 3 times more particles, 3 times more swiftly; the resistance is then 9; and so on.*

§ 146. *Resistance of Water.* The resistance of water to a moving body is greater than that of the atmosphere; water being less elastic, and its particles being not so easily removed, as those of the atmosphere. Without this resistance, there would be neither swimming, nor stirring, nor, in short, any voluntary motion, neither in water nor in the air.

Here it would be easy to explain the principles of swimming of men, animals, and fishes, the flying of birds, &c.

§ 147. If a stone or cannon-ball impinges, under a very acute angle, on a sheet of water, it will be reflected from it, without entering, and the angle of reflection will be equal to the angle of incidence. (§ 114, page 105.)

§ 148. Through friction and the resistance of the atmosphere, every body which is in motion must finally be brought to rest.

§ 149. If the infinite space in which all celestial bodies move, and in which our earth itself performs its orbit, is filled with a thin, subtile fluid, then the resistance of this fluid must necessarily modify their motion. The existence of such a fluid has been lately ascertained beyond a doubt.†

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* See Prof. Prechtle's experiments, in the Annals of the Polytechnic School in Vienna.

† See Tob. Mayer's Nat. Phil. page 168. Also, Schröter on Comets (Neueste Beiträge zur Erweiterung der Sternkunde, von Dr. Schröter. Göttingen, 1800).

Also, Schröter on the Comet of 1807.

RECAPITULATION.

QUESTIONS FOR REVIEWING THE MOST IMPORTANT PRINCIPLES CONTAINED IN CHAPTER III.

[§ 51.] What do you call the *absolute place* or position of a body? How are you led to the idea of *situation* or *relative position?* What do you call *motion?*

Can absolute motion be perceived through the medium of our senses? How, then, become we conscious of motion? Give examples. Why does absolute motion not come within the reach of our senses?

[§ 52.] *What do you call that state of a body in which it continues without motion or change of position?*

[§ 53.] Why do we say a moving body describes a line? What is this line called?

[§ 54.] What does every kind of motion require? Why?

[§ 55.] What leads us to the idea of *velocity?* How is velocity estimated? Which of two bodies is said to have the greatest velocity?

Give an example.

[§ 56.] When do you call the motion of a body *uniform?* When accelerated? When retarded?

Give an example.

[§ 57.] What power has every body in motion with regard to another body which it finds on its way? When do we say a body, A, has imparted motion to a body, B? What relation exists always between action and reaction? Why?

Give an example.

[§ 58.] *What must every motion, as well as every change of it in velocity or direction, proceed from?*

In what state would every body remain, without such a cause? What is this universal principle called? Give instances proving this principle. Which are the two principal obstacles or hindrances of motion? By what process of reasoning can the doctrine of *vis inertiæ* be established, independent of any experiment?

What other facts do you know, proving the correctness of this theory?

[§ 59.] What do you understand by the term *force?* When do we say that a body has received an *impulse?* What tendency does every such impulse give a body?

What are the principal moving forces in nature?

[§ 60.] *What does the imparting of motion require?*

How can you show this by an experiment?

Questions on the Laws of Motion.

[§ 61.] When is a body said to be in uniform motion? *What general law follows from this definition?* Of two bodies in uniform motion, during the same number of seconds, which is said to have the greater velocity? If the times are unequal, which of two bodies of the same velocity will describe the greater space?

In what proportion are the velocities of two bodies, A and B, of which the former has passed uniformly through 100 feet in 5 seconds, and the latter through 50 feet in 10 seconds?

[§ 62.] *How do you find the space described by a body in uniform motion?* Give an example. What is the space described by a body in uniform motion during 12 seconds, with a velocity of 5 rods per second? What that of a body in uniform motion during 10 minutes, with a velocity of 3 miles per minute?

[§ 63.] *In what proportion are the spaces described by two bodies in uniform motion?*

In what proportion are the spaces described by the two bodies A and B, of which the former has been in motion during 3 minutes, with a velocity of 5 feet per minute, and the latter during 5 minutes, with a velocity of 4 feet per minute? *In what proportion is the velocity of two bodies in uniform motion?* Suppose two bodies, A and B, had passed, A through 20 feet in 4 seconds, and B through 40 feet in 10 seconds, in what ratio are their velocities?

[§ 64.] *What power has every body in motion with regard to another body which it finds on its way?* On what

does the degree of this power depend? Which of two bodies, which move with the same velocity, will exercise the greater power? Which of two bodies, whose masses are equal, will produce the greater effect? *

[§ 65.] *How is the power of a body in motion measured?* What do you call the product of the mass into the velocity of a body? What is the momentum or moment of a body whose mass is 40 lbs., and velocity 40 feet per second? What that of a body whose mass is 100 lbs., and velocity 10 feet per second?

Give instances of small bodies producing greater effects by their velocities than large bodies with little velocity.

[§ 66.] *In what proportion must the power be which is requisite to impart to a body a certain velocity?* What power is required to impart to a body of 40 lbs. the velocity 5? What, to give the velocity 4 to a body whose mass is 10? Give instances from nature, in which a great velocity given to a small substance produces surprising effects. Give instances where a small velocity given to a large mass produces similar effects. *What, therefore, is necessary, in order that two bodies,* A *and* B, *shall have equal moments?* †

[§ 67.] *What is necessary, in order that a body shall move with uniform velocity?* How long, then, would the body continue in motion?

[§ 68.] What kind of motion does a power produce, which, after having communicated motion, continues to operate in the same direction during the following intervals of time? What is such a power called?

[§ 69.] What kind of motion takes place if the velocities imparted are in proportion to the times? What is the power which produces such a motion called?

[§ 70.] Which is the most remarkable uniformly accelerating power in nature?

[§ 71.] How can you satisfy yourself that gravity is really a uniformly accelerating power? Would it make any material difference if there were intervals in the operation of gravity? Why not?

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* Those pupils who are acquainted with algebra or geometry, may state the proportions in the note to page 55.

† How can you express the principles contained in § 65, § 66, mathematically?

What sort of pressure does every body exercise on the plane or basis on which it rests? What, therefore, can we infer from it?

[§ 72.] *Which are the four principal laws of falling bodies?* (The answer to this question is contained in the text in the italics, 1, 2, 3, 4.)

How can you prove that the space described by a free falling body, in a certain time, is always equal to the space through which it would have passed, had it moved uniformly, with half the final velocity? How can you prove that the spaces through which a falling body passes, in a succession of equal intervals, are in proportion to the odd numbers, 1, 3, 5, 7, &c.? How can you prove that the whole spaces described from the beginning are proportional to the squares of the whole times?* How can you prove the correctness of these laws by actual experiments? Explain Atwood's falling machine. (Fig. 11.)

[§ 73.] Through how many feet does a free falling body pass in the first second? *By what rule do you obtain a body's perpendicular descent?* †

Supposing you knew a body had freely fallen during the time of 5 seconds, how should you calculate its perpendicular descent? What rule is there for obtaining a body's perpendicular descent? If the space through which a body has fallen is known, how can you find the time? Supposing the body had fallen through a space of 400 feet, what would have been the whole time of its fall? What time would a body need to fall through the space of 576 feet? What time to fall through 1024 feet? What to fall through 16,000 feet? What phenomena do the laws of free falling bodies explain? What applications are made of these principles?

[§ 74.] Has the mass of a body any influence upon, or does it in any way modify the laws of falling bodies? Why not?

Is the falling of all bodies equally accelerated by gravity? What are all differences in time and velocity solely attributable to?

Explain the experiment represented in Fig. 12.

[§ 75.] How does gravity affect the motion of a perpendicularly ascending body?

Explain the table, page 65.

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* How can you express the four laws of uniformly accelerated motion mathematically?

† Express this rule mathematically.

Compound Motion, Resolution, and Composition of Forces.

[§ 76.] *If a body is, at the same time, solicited by two equal opposite forces, what must necessarily take place?* What are these forces said to be? *What will be the result, if the two forces, which act upon the body in opposite directions, are unequal?*

Explain Fig. 13.

[§ 77.] *If the directions of the two forces which solicit the body make an angle with each other, what direction will the body then follow?* How can you explain this by reasoning?

How can you prove it by an experiment? Explain Fig. 14. By what other experiment can you prove it? Explain Figs. 15 and 16.

[§ 78.] What do you call the motion you have just considered? *What are the two forces* AB *and* AC, *in Fig.* 14 *called? What do you call the force represented by the line* AM? *What relation exists between this force and the two forces* AB, AC? *What important law follows from this principle?* Explain Fig. 17.

[§ 79.] Can the principle of the resolution and composition of forces be applied also to three or more lateral forces? Explain Fig. 18.

Give examples of the resolution and composition of forces from nature. Explain the motion of a boat when crossing a river. (Fig. 19.) Explain the equestrian feats. (Fig. 20.) Give an example of the composition of forces. (Explain Fig. 21.) Explain the descent of a heavy body from an elevation of several hundred feet. (Explain Fig. 22.) Have experiments of this kind actually been made? Where?

Application of the Composition and Resolution of Forces to the Theory of Curvilinear Motion.

[§ 80.] If a body receives an impulse in one direction, and is, at the same time, continually attracted by another force, what kind of motion will then take place?

Ans. The body will, then, in every moment of its motion, be turned from its direction, and describe a curve line.

Quest. How can you show this? Explain Figs. 23 and 24.

[§ 81.] *What is the name of a force which attracts a body continually toward one and the same point? What is the name of that force which urges it continually to recede from that point in a straight line? What are both forces called?* If, at any time, one of these forces should cease to operate, in what direction would the body continue to move? What motion would take place, if the centripetal force only should remain? What, if only the centrifugal force remained?

On what does the nature of the curve line resulting from the joint action of the central forces depend? What line does a body describe, when the impulses of the centripetal force are inversely as the squares of the centrifugal force? To what motion does this apply?

[§ 82.] Is the attraction of gravitation the only centripetal force in nature? What other forces may be substituted for it? (Explain Fig. 25.) *In what proportion does the centrifugal force increase?* Explain Fig. 26.

[§ 83.] Does the experiment alluded to in § 82 undergo any material change, if, instead of a string, a solid hindrance were substituted? *What do you call a straight line, passing perpendicularly through the centre of a revolving body? What is the body said to do?*

Give an instance of this kind. Give examples of the joint action of centrifugal and centripetal forces. (Explain the experiment represented in Fig. 27.) What caution ought to be used in turning a carriage or vehicle round a corner? Why? How does the centrifugal force, generated by the revolution of the earth on its axis, affect the attraction of gravity? (Explain Fig. 28.) What other effect does the centrifugal force produce in the shape of our globe? Explain Fig. 29.

Further Application of the Theory of Composition and Resolution of Forces to the Curvilinear Motion of a Body thrown up at an Angle with the Direction of Gravity.

[§ 84.] If a body is thrown up in a direction making an oblique angle with the horizon, what kind of line will it describe? Why? Explain Fig. 30.

What is the name of the curve which the body thus describes?

[§ 85.] *If a heavy body is projected horizontally, that*

is, at right angles with the direction of gravity, in what time, independently of its velocity, will it reach the ground? Explain Fig. 31.

[§ 86.] *With what does the distance to which a projectile may be thrown increase, besides the horizontal velocity?* (Explain Fig. 32.) Explain the case when two bodies are both thrown with the same velocity, but from unequal heights? (Explain Fig. 33.) *In what proportion do the distances increase, when the velocities are equal?*

[§ 87.] On what does the sweep of the curve depend? Explain Fig. 34.

What motion of heavenly bodies is analogous to this?

[§ 88.] *What important truth have philosophers discovered in reference to the attraction of gravity?* To what other cases does this law apply?

Motion on an Inclined Plane.

[§ 89.] What do you understand by an inclined plane? What takes place if a heavy body is placed upon it?

[§ 90.] *What is the law of motion on an inclined plane?* How can you here apply the law of the decomposition of forces?

[§ 91.] *On what does the velocity of a body moving on an inclined plane depend?* What law is there respecting the angle of elevation? What motion takes place when the angle of elevation is a right angle? What takes place when the angle of elevation is zero, that is, when the plane is parallel to the horizon?

[§ 92.] *What power is required to stop the motion of a body on an inclined plane?* *

How can you show this by an experiment?

To what is the whole theory of motion on an inclined plane analogous? How may both theories be illustrated? (Explain Fig. 39.) What are the principal applications of the inclined plane?

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* Those who understand geometry may give the geometrical demonstration of this law, given in the note to page 83; and also the remarkable inference which may be drawn from the principle laid down in the note to that page.

Oscillations of a Pendulum.

[§ 93.] What do you call a pendulum? What a simple pendulum? What may be considered a simple pendulum?

[§ 94.] When a pendulum is raised from its perpendicular to an inclined position, and then let free again, what will take place? What do you call the angle by which the inclined position of the pendulum (to which it is raised) differs from the perpendicular direction?

How can you explain the operation of the pendulum? (Explain Fig. 40.) Why does the pendulum not continue to swing forever?

[§ 95.] *What is the most remarkable property of the pendulum? Is the duration of the oscillations of a pendulum influenced by the length of the arc which it describes?*

[§ 96.] *On what does the time which is needed for one oscillation depend? What law is there with regard to this dependency? Give examples of the application of this law.**

[§ 97.] *What are the uses of the pendulum?* (Explain Fig. 41.) *What laws in reference to terrestrial gravity are we enabled to prove with the pendulum? What is the pendulum the best regulator of?* What is the only modification to which a pendulum is subjected? How is this obviated? Explain Fig. 42.

Of the Lever.

[§ 98.] What do you call a *lever?* What is the point in which the lever is supported called? What do you call the *arms of the lever?*

[§ 99.] When two forces act upon the lever, by what names do you distinguish them from one another?

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* Are these accelerations uniform? Why not? If T, t, respectively, represent the times needed for one oscillation, and L, l, the respective length of the pendulums, how may these proportions be expressed mathematically? By what formula is the whole duration of an oscillation expressed? What does this formula enable us to find?

[§ 100.] How many different kinds of levers are there? Explain Figs. 44, 45, 46.

[§ 101.] *What is the principal law of the lever?* Give an example. When is the power in equilibrium with the weight?

How can you prove this law by actual experiments? Explain Figs. 47, 48, 49, and 50.
If the directions of the power and weight are not perpendicular to the arms of the lever, but act at oblique angles, how, then, do you obtain the distances of the weight and power from the fulcrum? (Explain Fig. 51.) What is the law with regard to the rectangular lever? Explain Fig. 52.

[§ 102.] *What is the condition of equilibrium when there are several powers and weights operating on the lever?* If some of these powers or weights act in opposite directions, what must you do with their moments?

Explain Fig. 54.*

[§ 103.] What do you understand by a *compound lever?* (Explain Fig. 55.) How is the power of such an arrangement calculated? Does the advantage of such an arrangement only consist in the gain of power? In what else does it consist? Give an example.

What are the principal uses of the lever? Give examples of lever power.

Of the Centre of Gravity.

[§ 104.] What is the point called in which an inflexible straight bar, charged with several weights, must be supported, in order that it shall neither move in one way or another? By what law may it be found?

[§ 105.] What is the pressure which such a bar exercises upon the prop which supports it, equal to? Give examples.

[§ 106.] *What may every heavy body be taken for?* How can you convince me that in every heavy body there is a point in which the whole weight is active? Explain Fig. 57.

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* How can you prove the principal law of the lever mathematically?

[§ 107.] What is the name of a vertical line drawn through the centre of gravity of a body? What must take place if this line is in any point supported or fixed? How can you find such a point?

In what point is the centre of gravity in a uniformly dense body? Give examples. In which point is the centre of gravity in the regular solids, the tetrahedron, the octahedron, cube, &c.? In which point is the centre of gravity of a prism or cylinder of uniform thickness?

How do you find the centre of gravity of a triangle? (Explain Fig. 66.) How may this be proved by an experiment with a thin piece of card?

How could you find the centre of gravity of any other rectilinear figure? Explain Fig. 67.

How do you find the centre of gravity of an inflexible bar with unequal weights upon it? Explain Fig. 68.

Is the centre of gravity always within the body? Give an instance where the centre of gravity lies without the body.

In what manner may the centre of gravity be determined by experiments? Explain Figs. 70 and 71.

[§ 108.] When a body is placed upon a basis, on what does its stability depend? If the line of direction falls without the basis, when will it stand firm, and when will it be liable to turn over? What will occur when the line of direction falls without the basis?

Why does a pyramid (Fig. 72) stand firmer than a body shaped as represented in Fig. 73? (Explain both figures.) What must be the position of a plane, in order that a ball shall rest upon it? Why can a ball not rest on an *inclined* plane?

What phenomena are explained by the theory of the centre of gravity?

Laws of Percussion.

[§ 109.] When a moving body meets another on its way, what must necessarily take place? If the line in which the centre of the striking body moves passes also through the centre of the body on which it strikes, what is the stroke or percussion called? What is it called, when this line does not pass through the centre of the body which is struck?

[§ 110.] *Which are the three principal cases which can occur in the percussion of bodies?*

1. *Laws of Percussion of Unelastic Bodies.*

[§ 111.] *How many cases can there occur in the percussion of unelastic bodies? Which are they? What will take place in the first of these cases? What in the second? What in the third?*

How can you illustrate these laws? Explain Figs. 76, 77, and 78.

2. *Laws of Percussion of Elastic Bodies.*

[§ 112.] *What is the principal law in the percussion of elastic bodies?* Give examples.

[§ 113.] How many different cases can there occur in the percussion of elastic bodies? Which are they? *What must take place in the first case? What in the second? What in the third?*

How can you illustrate these three cases? Explain Figs. 79, 80, and 81.

[§ 114.] *What law is there for the case in which an elastic body impinges against an unelastic firm plane? or an unelastic body against an elastic firm plane?* What will occur when the angle of incidence is a right angle?

How can you prove this law by the decomposition of forces? Explain Fig. 82.

[§ 115.] When several elastic balls, of equal size, are suspended in such a way that their centres lie all in the same straight line, and the first is raised from its position, and let fall again, so as to strike upon the second, what will then take place? Can you explain this phenomenon from the laws of percussion of elastic bodies? *

Vibrating Motion—Acoustics.

[§ 116.] How is sound produced? and what is necessary in order that a body shall produce sound?

How may the vibrations which are productive of sound be made visible? What do these experiments prove?

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* Let the pupil recur to the second case.

[§ 117.] What is necessary in order that we shall *hear* the sound of sonorous bodies? What do we denote by the word *hearing?*

[§ 118.] What is the medium through which sound is generally propagated? What other bodies are capable of propagating sound?

How may this be shown by experiments?

[§ 119.] What do the vibrations which a sounding body produces in the surrounding atmosphere consist in?

What phenomena are thereby explained?

[§ 120.] What property must a body possess, in order that it shall be capable of producing sound? Why can a body without elasticity produce no sound? With what does the capacity of a body for sound increase?

[§ 121.] Is the whole uninterrupted surface of a sonorous body thrown into a vibrating motion, or are there certain points or lines which remain in a state of rest? What does frequently take place when a chord vibrates?

By what experiments may the points and lines which remain in the state of rest, while the rest of the sonorous body is vibrating, be exhibited? By whom was this discovery first made? What other still more striking experiment can you mention?

[§ 122.] Is the sound prevented or modified when the places which are exempt from the vibrations of a sonorous body are touched with the finger? What takes place when a sonorous body is touched in any other place, or brought in contact with some other body?

In what manner does a vibrating chord divide itself? (Explain Fig. 85.) What experiment can you make with such a chord? What other phenomena are explained on the same principle?

[§ 123.] On what does the *height* or *depth* (acuteness or gravity) of sound depend?

To what theory may the vibrations of a chord be reduced? What proportion does the acuteness of sound bear to the tensions, the lengths, and the thicknesses, of the chords? *

[§ 124.] If the thicknesses and tensions are the same, on what does the number of vibrations then depend?

* The pupils who have studied geometry ought to state the proportions in the note to page 108.

[§ 125.] When will two chords produce the same tone? What are two chords which give the same tone, said to be?

When a chord is struck, what does an experienced ear always distinguish, besides the principal tone? In what does this phenomenon probably originate? How is an Æolian harp constructed? How must it be tuned? How do the chords of this instrument vibrate when exposed to a gentle draft?

[§ 126.] When a chord, *c*, makes, in the same time, twice as many vibrations as another chord, C, what is it called? What is a chord, G, called, which makes three vibrations, while C makes two? What is the name of a chord, *c*, which makes four vibrations to the chord G's making three?

What is the ratio of the fundamental tone to its next higher octave? What that of the *quint* to the fundamental tone? What that of the quint to its quart, which is at the same time the octave of the fundamental tone? What do these three notes form? What are they said to have formed?

[§ 127.] How many principal tones are there in an octave? By what letters are they designated, and what are they called? What are these seven tones called in music?

[§ 128.] What do you understand by the *numerical value* of a tone or note? If the fundamental tone is 1, what is the value of the next higher octave? What that of the next higher quint? What that of the next lower quint? What that of the next higher quart? What that of the next lower quart?

What are the numerical values of the seven tones of the diatonic scale, derived from those just given?

[§ 129.] What is the ratio of one tone to another called?

[§ 130.] Are the successive intervals between the seven tones of the diatonic scale equal to one another? Give instances where they are unequal.

[§ 131.] Does the diatonic scale satisfy the demands of modern music? What scale is used in its stead? Wherein does the chromatic scale differ from the diatonic scale?

What are the five additional semitones called, which, in the chromatic scale, are inserted between C and D, D and E, F and G, G and A, and A and B?

What are the numerical values of these notes?* The numerical values of the notes A and E, in the chromatic scale, differ a little from those which these notes have in the diatonic scale: what was this impurity of sound introduced for? Where is it absolutely indispensable? Is there any instrument which can give every interval as clear and perfect as the human voice? Which is the most perfect of all?

[§ 132.] What do you understand by *harmony* or *concord?* What by discord or dissonance? Give examples of both.

[§ 133.] What does *melody* consist in? Wherein consist the difficulty and beauty of musical composition?

[§ 134.] Are very high or very low tones still audible? How many octaves comprise nearly the whole system of notes fit for music? How is the deepest audible sound produced?

[§ 135.] What kind of vibrations does a common violin string make when the bow is drawn under a very acute angle? What sensation does such a sound produce in the ear? Is the sound higher or lower than the natural tone of the chord produced by transversal vibrations?

Does the height or acuteness of the sound thus produced depend upon the thickness or tension of the chords? On what, then, does it depend? What does this phenomenon explain?

[§ 136.] Can you tell the velocity with which sound is propagated through the air?

By what is the propagation of sound through air modified? Why can a loud sound be heard farther than a low one? What do you know about the propagation of sound through solid bodies?

[§ 137.] As what may the vibrations which every sonorous body causes in the surrounding atmosphere be considered? Why is the sound heard better in the neighborhood of the sonorous body than at a distance from it? What law is there with regard to the intensity of sound? Give an example.†

[§ 138.] What takes place when a ray of sound strikes

* This question the teacher may put or omit at pleasure.
† How can you prove this law mathematically? Fig. 87.

on a firm plane? Is the whole ray of sound reflected, or only the few particles, which, in their vibrations, strike the plane? What remarkable phenomenon is thereby explained? What instrument does it show the utility of? How is the acoustic tube constructed?

What takes place when a ray of sound meets a plane surface at right angles? (Explain Fig. 88.) What, when it strikes that surface at an oblique angle? (Explain Fig. 89.) In what cases are several echoes heard? (Explain Fig. 90.) How is the sound emanating from the centre of a circular hall reflected? (Explain Fig. 91.) If the hall be eliptical, and the sound emanate from one of the foci, in what manner will it then be reflected? What is a hall built in this manner called? Why? How is the voice thrown into a speaking trumpet reflected from its sides?

[§ 139.] How does the air vibrate, which is blown into flutes, trumpets, horns, or other wind instruments? By what means are the different notes obtained from these instruments?

What is the reason that the sound is not prevented, when these instruments are touched with the hand? Why is it not so with chords or bells? Why can bassoons and flutes not be made of metal? Why are highly-elastic metals, such as silver and brass, unfit for the building of organs? Why do speaking trumpets made of metal convey the articulated voice less distinctly than those made of pasteboard or wood?

Obstacles or Hindrances of Motion.

[§ 140.] *Is there a body in nature that has a perfectly smooth and even surface?* What does always take place when two bodies, ever so well polished, move upon one another? What do you call this resistance?

[§ 141.] Can the laws of friction be fixed with precision? Why not? What principles, however, are we enabled to lay down from experience?

[§ 142.] What obstacle does every body, whose weight is wholly supported by a horizontal plane, present to the least change of place? What other phenomena are explained by friction?

Why is a cask moved more easily than a box? Can you now perceive the use of the pulley?

[§ 143.] By what means can friction be avoided in machinery?

[§ 144.] What other obstacle to motion is there besides friction? *On what does the resistance of the atmosphere principally depend? and in what proportion does it increase?*

[§ 145.] What proportion is there respecting the resistance of the atmosphere, and the velocity of the moving body?

How can you convince me of the correctness of this law?

[§ 146.] Why is the resistance of water to a moving body greater than that of the atmosphere? What processes are by the resistance of water rendered possible?

[§ 147.] What takes place if a stone or cannon-ball impinges under a very acute angle?

[§ 148.] What is the final effect of friction, and the resistance of the atmosphere on every body which is in motion?

[§ 149.] If the infinite space in which the celestial bodies move, and in which our globe itself performs its orbit, is filled with a subtile fluid, similar to the atmosphere, what effect must it naturally produce?

CHAPTER IV.

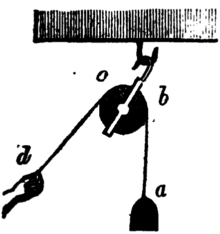
OF THE SIX SIMPLE MACHINES;—THE LEVER, THE INCLINED PLANE, THE PULLEY, THE WHEEL AND AXLE, THE WEDGE, AND THE SCREW.

§ 150. THE laws of the lever and the inclined plane have already been treated of in the preceding chapter, as far as they can be explained in an elementary treatise of this nature; it therefore remains for us only to speak of the *pulley*, the *wheel and axle*, the *wedge*, and the *screw*. All these simple machines, together with their compounds, may be reduced to the principle of the lever and inclined plane, as we shall see in the course of this treatise.

OF THE PULLEY.

§ 151. A *pulley* is a solid circle or wheel, with a grooved circumference, and an axis passing perpendicularly through its centre, and a case or frame-work called the *block*. When a rope is applied to the groove of this wheel, fixed in its position, as represented in Fig. 94, the machine is called a *fixed* pulley. In this pulley, the directions of the power and the weight are both *tangents* to the circumference of the wheel. Now, it is easily perceived that, in this case, the tension of the cord, *abcd*, is *uniform* throughout: the weight stretches the part *ba*, between it and the pulley, and the power stretches the part *cd*, between the

Fig. 94.



power and the pulley. Hence, since the tension is the same throughout the whole length of the rope, the weight must be equal to the power, and it is evident that no other advantage is obtained from this arrangement than a change in the *direction* of the power.* There is, nevertheless, scarcely a machine attended with more convenience; especially when the power applied to the pulley consists in the strength of men or animals, which is always exerted to the greatest advantage in certain directions. Thus a man will find it most convenient to pull the rope, *cd*, downwards, as represented in Fig. 94. A horse, on the contrary, will be used to the greatest advantage by an arrangement similar to that represented in Fig. 95, by which heavy burthens may be raised to the window or roof of a building. In all such cases, the change in the direction of the power is as advantageous as an actual gain in the power itself, and even more so.

Fig. 95.

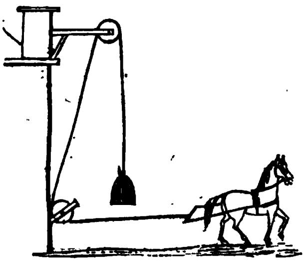
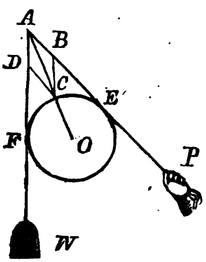


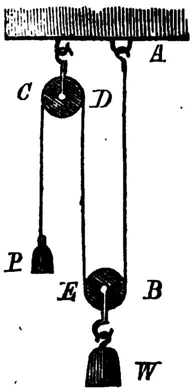
Fig. 96.



* The same result may be obtained *mathematically*, by the decomposition of the two forces EW and FP, in the following manner:—Produce EW and FP until they meet in the point A. Upon AP and AW, respectively, take the two distances AB, AD, equal to one another. These may represent the two forces W and P. Now, as AF and AE are tangents to the pulley, it follows that the diagonal or resultant, AC (§ 78, page 68), must pass through the centre, O, of the pulley; consequently, if the pulley be fixed in that point, no motion will take place as long as the power, P, is equal to the weight, W.

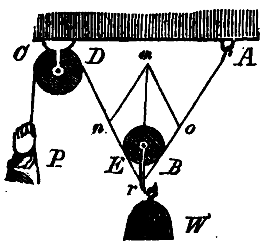
§ 152. When the weight or resistance is applied to the centre of the pulley, or at least in a direction passing through the centre, whilst one end of the rope is fixed to some solid block, the machine is called a *movable* pulley. Fig. 97 represents such an arrangement. The cord AB, attached to the fixed point A, passes through the block EB, to the centre of which is applied the weight, W, and is carried round the fixed pulley, CD, the power being applied in P. To understand the advantage of such an arrangement, let us at first suppose the directions AB, DE, to be parallel to one another. In this case, the whole weight, W, is sustained by the tension of the two parts AB, DE, of the rope; and as the tensions of these two parts are equal (§ 151), each must sustain half the weight; consequently, the part DE will only be stretched with one half of the weight, W; and the power, P, being in the fixed pulley, CD, equal to the tension DE, will also be but one half of the weight W. *Hence, in the movable pulley, the power is but half of the weight.*

Fig. 97.



§ 153. If the directions of the cords AB, DE, are not parallel, but inclined to each other by any angle at pleasure, the relation of the power to the weight may easily be found by the rule for the decomposition of forces. (See § 78, page 68.) In the direction m W, take the distance mr, equal to as many inches as there are pounds or ounces in the weight, W, and draw the lines mn, mo, parallel to AB and DE respectively. The parallelogram $rnmo$ will have all its sides equal; because the tensions nr and ro are equal to each other; hence the pow-

Fig. 98.



er, P (which is equal to the tension represented by *nr*), is to the weight, W, as any one side of the parallelogram *mnor* is to its diagonal.*

It is to be observed here, that, as two sides of a parallelogram are together always greater than the diagonal, *mn* and *nr* together must be less than *mr;* but *mn* and *nr*, together, represent *twice* the power, whilst the diagonal *nr* represents the weight; hence *the weight in this arrangement is always less than double the power*, in proportion as the directions DE, BA, vary from the state of parallelism.

§ 154. The mechanical power of the pulley may be much increased by combination. Such an arrangement is then called a *system* of pulleys. One of these systems is

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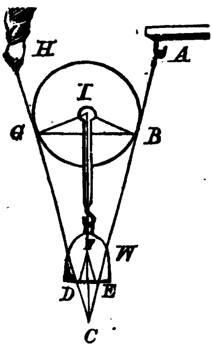
* It can be mathematically proved, that *the tension of either part of the rope is to the weight at the centre as the radius of the pulley is to the chord of the arc embraced by the rope.* Let AB, HG (Fig. 99), be produced until they meet in a point, C. Upon BC and GC, take DC, EC, equal to one another, and construct the parallelogram FDEC: FC will represent the resultant of the tensions of the rope represented by DC and CE respectively. Draw the radii IG, IB, and the chord GB. The triangle GIB having its three sides, respectively, perpendicular to the three sides of the triangle DCF, these two triangles will be similar to each other, and give the proportion

GI : GB : : DC : FC.

(Grund's Plane Geometry, Section II.)

But GI is the radius of the pulley, GB the chord of the arc embraced by the rope; DC represents the power, and FC the weight; hence the above proportion expresses the law which was to be proved.

Fig. 99.



REMARK. When the directions HG, AB, of the rope are parallel to each other, the chord, GB, becomes a diameter; in which case the above proportion changes into

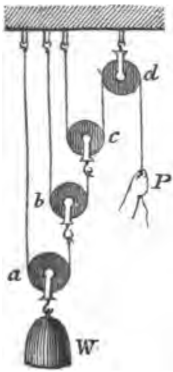
r : 2r : : p : w;

in which r stands for radius; 2r for double the radius, or the diameter; p for power, and w for the weight; which proportion is the same as this—

p : w : : 1 : 2;

and agrees with the law stated above in § 152.

Fig. 100.

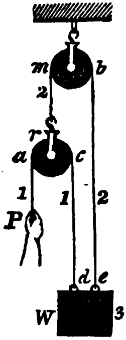


represented in Fig. 100: *a, b, c*, are movable pulleys, embraced each by a rope, one extremity of which is attached to a fixed point, and the other to the block of a pulley; *d* is a fixed pulley; and the power, *P*, is applied in the direction *dP*. In this system, the power of one pulley acts as weight to the next pulley, &c. Hence the weight, W, is 8 times the power, *P*.

This may be easily understood from the following course of reasoning:—The directions of the forces being parallel to each other, the weight, W, is to the power of that pulley as 2 to 1; but the power of the pulley *a*, being the weight of the pulley *b*, is to the power of the latter again as 2 to 1; and as the power of that pulley acts, in its turn, as the weight to the pulley *c*, its proportion is to the power, *P*, again as 2 to 1. Hence the ultimate ratio of the weight, W, to the power, *P*, is as $2 \times 2 \times 2$ is to $1 \times 1 \times 1$; or, which is the same, as 8 to 1; which was to be proved. It is easily perceived that, by adding another movable pulley, the rate of the weight to the power would be as 16 : 1; and so on.*

§ 155. Fig. 101 represents an arrangement of a single rope, which, by means of one movable pulley, supports a weight equal to three times the power. Indeed, if the tension produced by the power, P, in the direction *a* P, is represented by 1, the weight which the tension of the part *cd* will raise, will also be represented by 1; because the pulley, *ac*, acts in reference to the weight, W, as a fixed pulley. Both these tensions stretch the rope *mr*, with a power expressed by 2, and the tension in the direction *be* being consequently also equal to 2, the weight, W, will be supported by the tensions 1 and 2 of the two ropes *cd*, *be*, respectively; hence the weight, W, is, in this machine, 3 times the power, P.

Fig. 101.



* The general expression of the ratio of the weight to the power of *n* movable pulleys arranged in the above manner, is 2^n, the power taken as unity.

A similar power is produced by the arrangement represented in Fig. 102, where the respective tensions of the cords, and their united effect, are represented by numbers. By combining these pulleys in a manner similar to those represented in the figure, we may obtain a machine, in which the power is to the weight as 1 is to 9, to 21, to 81, &c.

Fig. 102.

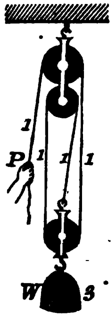


Fig. 103.

For the sake of compactness, a system of pulleys is often arranged in two blocks, one containing all the fixed pulleys, and the other all the movable ones. Such an arrangement is represented in Fig. 103.

When several sets of pulleys are employed, the power is to the weight always as 1 *is to the product of all the weights.* Thus, if two sets of pulleys are employed, in which the power of the first acts as weight upon the second, and the weight in the first is 5 times the power, whilst the weight of the second is 6 times the power, the united effect of these two sets will be 30 times the power.

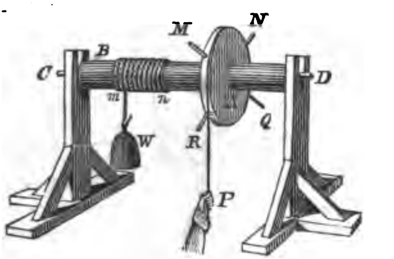
§ 156. We have seen, in the preceding sections, that the power of the pulley may be indefinitely increased by combination; but the mechanical advantage derived from all such arrangements is considerably less in practice than in theory, on account of the stiffness of the ropes and the friction of the wheels and blocks. These hindrances are, in most cases, so considerable as even to destroy two thirds of the power, and deprive the machine of a great part of its usefulness.

The principal uses of the pulley consist in raising weights to great elevations; and its chief application is in the rigging of ships, where almost every motion is facilitated by its means.

OF THE WHEEL AND AXLE.

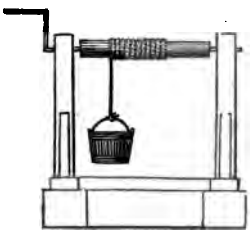
§ 157. The wheel and axle is a machine which consists of a grooved wheel, A (see the figure), and a cylinder, B, passing perpendicularly through the centre of the wheel, and resting, at its extremities, upon two fixed supports, C, D. The power, P, applied to the circumference of the wheel, turns this wheel and the cylinder which is fixed to it; and the latter, by its rotary motion, takes up successively the different parts of the rope, *mn*, to which is attached the weight, W, which is to be drawn toward the cylinder.

Fig. 104.



Instead of a wheel, the spokes, M, N, R, Q, may be used, to the extremities of which the power may be applied with the same effect as if the point of application were in the circumference of a wheel of which the spokes represent the radii.

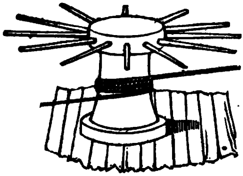
Fig. 105.



Or the cylinder may be provided with a winch, as represented in Fig. 105, in which case the machine is called a *windlass*.

§ 158. When the axis of the cylinder is vertical, as represented in Fig. 106, the machine is called a *capstan*. In this form it is used on board of vessels, only that, in this case, the figure of the axis is conical, to prevent the rope from slipping when it has reached the lowest point.

Fig. 106.



§ 159. The principle on which the wheel and axle act, is easily determined, and may be reduced to that of a lever, whose fulcrum is in the axis of the cylinder, B (Fig. 104), and whose two arms are the radius of the cylinder and the radius of the wheel, respectively. Hence *the ratio of the power to the weight is, in this arrangement, the same as that of the radius of the cylinder, or axle, to the radius of the wheel*. Thus, if the radius of the wheel is 3 times as great as that of the axle, the weight will be 3 times the power; if it were 4 times as great, the weight would be 4 times the power; and so on. And it can make no difference whether the power is applied immediately to the circumference of the wheel, or to the spokes, M,N,O,Q, (Fig. 104), or to the winch (Fig. 105), only that, in the two last cases, the length of the spokes, or the distance of the handle of the winch, from the centre of the axis, must be taken for the radius of the wheel.*

§ 160. From what has been said in the preceding paragraph, it would appear as if the power of the wheel and axle could be increased indefinitely, either by increasing the diameter of the wheel, or by diminishing that of the axle; but the advantages thereby obtained are limited in practice; because, by making the wheel too large, the power has to move through too large a space, and, by diminishing the diameter of the axle, the latter may become too feeble for the support of

* If the radius of the axle is represented by r, and that of the wheel by R, the proportion of the power to the weight may be expressed as follows:

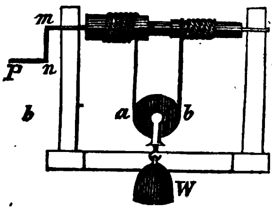
$$p : W :: r : R;$$

or, because the radii of circles are in the same proportion as the diameters,

$$p : W :: d : D.$$

a heavy weight. These inconveniences are partly remedied by giving the axle different thicknesses (as represented in Fig. 107), and carrying a rope, which is coiled on the thinner part, over a pulley attached to the weight, W, and coiling it, in the opposite direction, on the thicker part. In this arrangement, the weight will only move with the difference between the circumferences of the thicker and thinner part of the axle; because the rope uncoils from the thinner part, whilst it coils on the thicker; but the power is greatly increased, as we shall see from the following considerations:—

Fig. 107.



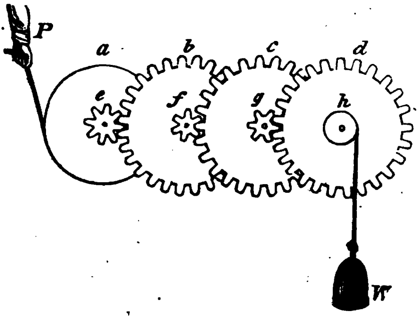
The tension of the two parts, *a* and *b*, of the rope, are evidently equal, each supporting half the weight, W; hence the moment acting on the circumference of the thinner part of the axle is half the weight multiplied by the radius of that part of the axle; and the moment acting on the circumference of the thicker part is equal to the radius of that part multiplied by half the weight. Now, it must be observed, that the moment acting on the thinner part *assists* the power, P; because the rope uncoils from the thinner part of the axle in the same direction in which the winch, *mn*, is turned; consequently *the power*, P, *multiplied by the radius of the wheel or winch, need only be equal to the* DIFFERENCE *between the two moments on the axle;* that is, *to the difference between the radii of the thicker and thinner part multiplied by half the weight;* or, which is the same, the power, P, multiplied by the diameter of the wheel, need only be equal to half the difference between the radii of the thicker and thinner part of the axle, multiplied by the weight. *This arrangement, therefore, is equivalent to a common wheel and axle, in which the wheel is of the same diameter, but the diameter of the axle only half the difference between the thicker and thinner part.*

§ 161. The uses of the wheel and axle are the same as those of the lever; because heavy burthens may, by its means, be raised by a comparatively small force; but its

greatest advantage consists in the continuity of its action; on which account it has also been called the *perpetual lever*. When a lever is used to raise a weight, it acts only through a small space, after which it must return to its first position, in order to renew the action. Hence the common lever is only used for weights which are to be moved through small spaces; but where a continuous motion is to be produced, the wheel and axle must be employed.

§ 162. In cases where great power is required, the wheel and axle may be combined, like a system of levers. Fig. 108 represents such a combination. The power, P, which acts on the circumference of the first wheel, *a*, is, by means of the pinion *e*, transmitted to the circumferences of the second wheel, *b*; that wheel acts by its pinion, *f*, upon the circumference of the third wheel; and so on. It is at once evident, from inspection, that *the united power of such an arrangement is to the weight as the product of the radii of all the axles, or pinions, is to the product of the radii of all the wheels of which it is compounded.* Thus, if the radius of each single wheel, in Fig. 108, is 10 times that of the pinion, the weight of the whole combination will be $10 \times 10 \times 10 \times 10 = 10{,}000$ times the power; and in the same manner it may be computed for any other number of wheels.

Fig. 108.



REMARK. In order that the wheels and pinions of such a machine shall work together, the teeth must evidently be of the same size; consequently the proportion of their circumferences may also be estimated by the number of teeth which they carry; that is, in the computation of the power, the number of teeth will always express the circumferences, or their diameters, to which they are proportional.

§ 163. The pinions, *e*, *f*, *g*, *h* (see Fig. 108), revolve, evidently, much more frequently than the wheels to which they impart motion; and the velocity of the pinion is evidently to the velocity of that wheel inversely as the number of teeth which they carry. Thus, if the wheel has 100 teeth, and the pinion only 10, the pinion will revolve ten times to the wheel's turning round once; and by this means their respective velocity may be determined.

OF THE WEDGE.

§ 164. The wedge is an application of the inclined plane (§ 89, Chapter III), and consists of a triangular prism, *a b c* (see the figure), which is employed either for enlarging a cleft into which it is introduced, or for separating two surfaces from each other, or to keep two surfaces at a determinate distance.

Fig. 109.

§ 165. The power of the wedge is not so easily calculated as that of the other simple machines, on account of the immense friction of the sides of the wedge against the surfaces of the cleft, and the unequal action of the power which is applied to the back of the wedge; for the power, being generally exercised by a hammer, acts at intervals, and not continually, as in other machines.

Another difficulty, which occurs in the computation of the power of the wedge, arises from the fact, that, when applied to the back of the wedge, a part of it is simply employed in bending the two branches of the cleft, whilst the rest is spent in distending the fibres which are not yet separated. To all these difficulties

we must yet add the differences in the textures of the bodies which are to be separated or divided, their adherence, elasticity, &c., all which properties influence the results of the wedge in practice.*

§ 166. The applications of the wedge are numerous, and of incalculable advantage in the mechanic arts. All cutting instruments—knives, scissors, razors, hatchets, chisels, &c.—act as wedges, or may be referred to its theory; also all piercing instruments, such as nails, stakes, piles, &c. In all these cases, we can only lay down the rule, that *the power of the wedge is increased by rendering its angle more and more acute;* but we must not forget that, by making the angle too acute, the edge of the wedge may be easily bent or broken; so that even this has its limits, and must, in a measure, depend on the degree of resistance which the wedge meets from the surfaces against which it is exerted.

A nail driven into a piece of wood, or into a wall, acts first as a wedge, and is afterwards retained in its position by the friction of its surfaces against the sides of the cleft. A saw consists of a series of wedges, the motion being oblique to the resistance. A wimble is a combination of the screw and wedge.

OF THE SCREW.

§ 167. The *screw* is another application of the inclined plane. It consists of a cylinder, with a protuberance raised on its surface, called the *thread*, which is carried round obliquely and continually at the same inclination to the axis. This screw, which is also called the *convex* or *external* screw, is made to fit exactly into another, called the *nut*, which consists of a hollow cylinder with a spiral groove cut

* Abstracting from friction, &c., it can be proved mathematically, that if the power is represented by the back of the wedge, the forces exerted on its sides, when that power is applied to the back of the wedge, are represented by the sides themselves. Hence, if the back of the wedge is denoted by B, the two sides by S, s, respectively, the power applied to the back by P, and the forces exerted against the two sides by Q, q, respectively, we have the proportion

$$P : Q : q :: B : S : s.$$

upon the inner surface, and is also known by the name of *internal* or *concave* screw.

This machine is used in two ways: either the nut is fixed, and the screw, by being turned, has its thread successively carried through the nut, or the screw is fixed, and the nut is turned to pass along the whole length of the thread. Fig. 110 represents the first, and Fig. 111 the second of these arrangements.

Fig. 110.

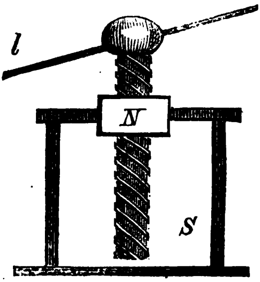
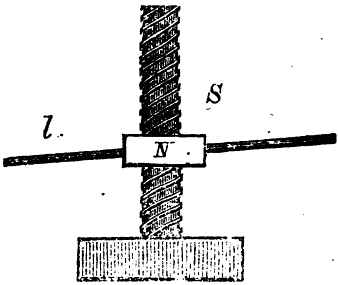


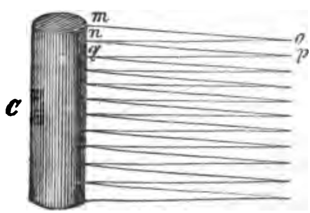
Fig. 111.



Either of these arrangements it is customary to combine with a lever power, *l*, which in Fig. 110, is attached to the screw, and in Fig. 111, to the nut.

§ 168. To understand the relation of the power to the resistance in this machine, we may consider the thread as formed by wrapping round the cylinder, C (Fig. 112), as many inclined planes *mno*, *npq*, &c., as there are revolutions of the thread, each of these inclined planes having for its height the distance between two adjacent threads, and for its base the circumference of the cylinder. When the screw is in a vertical position, and is, by virtue of its weight, or by some other force, urged downwards, it will slide down the

Fig. 112.



thread in the same manner as a weight would slide down the inclined planes, *mo*, *np*, &c. To overcome this tendency, which is called the *resistance* of the screw, the power exerted on the nut must be to it in the same ratio as the height, *mn*, of *one* of the inclined planes is to its basis, *on*; but the height, *mn*, is the distance between two adjacent threads, and the base, *on*, is nothing else than the circumference of the cylinder; hence *the ratio of the power to the resistance of the screw, is as the distance between two adjacent threads to the circumference of the cylinder.* The smaller, therefore, the distance between the threads, or the greater the diameter of the cylinder, the greater will be the power of the screw.

§ 169. The ratio of the power to the resistance, which we have just found (§ 168), applies only to those points of the nut which are in actual contact with the screw. But if the force, as is the case in practice, is applied, at a horizontal distance from the screw, by means of a lever, *l* (see Figs. 110, 111), then the power may be as many times less as its distance from the centre of the axis is greater than the radius of the cylinder, because this is the law of the lever. Hence the advantage of the machine increases also with the length of the lever, *l*; and, as this lever, when the screw is used, describes the circumference of a circle, we shall also have the following law:—*The power applied to the screw is to the resistance inversely as the circumference described by the point to which the power is applied is to the distance between two adjacent threads.* Thus, upon the same screw, the power will be more advantageously employed, according as its distance from the axis increases; and upon different screws, to which the power is applied at the same distance, the effect increases as the distance between the threads diminishes.* This law, however, obtained solely by mathe-

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* If p stands for the power, r for the resistance, D for the distance at which the power is applied from the axis, and h for the distance between two adjacent threads, then, because 2π represents the circumference of a circle whose radius is 1, the above proportion may be expressed as follows:—

$$p : r :: h : 2\pi D;$$

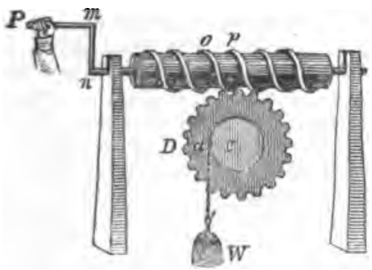
and as π represents the number 3.1415926, we may express the same proportion also by saying,

matical reasoning, is greatly modified in practice by the friction between the surfaces of the concave and convex screws.

§ 170. The screw is principally employed when great pressure is to be produced through small spaces. Hence it is not only used in the mechanic arts, in printing, bookbinding, and manufactories of all kinds, but it is also used, in many cases, where liquids are to be extracted from solids, in the coining of money, in compressing the bulk of substances, &c.

§ 171. The screw may be very advantageously combined with the wheel and axle, as represented in Fig. 113. The screw, instead of fitting to a nut, is applied to the teeth of a wheel, which, on its axle, carries the weight, W, which it is proposed to raise. When the screw is turned by the winch, *mn*P, the threads *o*, *p*, &c. act upon the wheel, CD, and cause it to be turned, together with the axle, *cd*, which raises the weight. Such an arrangement is called a *perpetual screw*. Its power may easily be calculated from the laws of the screw, and the wheel and axle, of which it is compounded.

Fig. 113.



In the first place, the power applied to the screw is to its resistance as the distance, *op*, between two adjacent threads is to the circumference described by the radius, *mn*. (See § 169.) But this resistance, acting as the power to the wheel and axle, is to the weight, W, as the radius of the axle is to that of the wheel (§ 159); consequently, *the power of the whole machine is to the weight as the distance between two adjacent threads multiplied by the radius of the axle is to the circumference described by the winch multiplied by the radius of the wheel.**

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* If R, r, respectively, denote the radii of the wheel and axle, h the distance of two threads, D the distance at which the power, P, acts from the axis of the screw, and W the weight which is to be raised, then the above proportion may be expressed mathematically by

$$P : W :: r \times h : 2\pi D \times R.$$

EXAMPLE. Suppose the distance between two adjacent threads of the screw is 2 inches, the length, *mn*, of the winch 10 inches, the radius of the wheel 24 inches, and the radius of the axle 3 inches; then the power would be to the weight as $2 \times 3 : 6.2831852 \times 24 \times 10$ (see note to page 149); or, which is the same, as 6 to 1507.964448, independent of the friction of the machine.

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§ 172. The five simple machines—the lever, the inclined plane, the pulley, the wheel and axle, the wedge, and the screw—are called the *prime movers;* because, by combining them, as the occasion requires, the various machines are obtained which are employed in manufactories and the mechanic arts. Thus, in a steam engine, all that the piston does is to act as a power on a lever or wheel, which is so connected with the rest of the machine as to give to every part the desired motion. In a mill, the power of the water or wind sets a wheel in motion, which, by its revolution, gives to every part of the arrangement the desired impulse. In a power or steam press, the single motion of the piston of the engine, acting as a power to a lever or wheel, effects all the motion required for printing, save that of putting on the paper, &c.

§ 173. We have seen, in the preceding sections, that a machine is an arrangement by which a small power is able to support or raise a weight of much greater magnitude. Thus we have seen, in § 103, that, in the compound lever, the small power of 1 lb. may be in equilibrium with a weight of 1000 lbs., so that it may be said that the power of 1 lb. sustains 1000 lbs. This, at first sight, seems to involve an impossibility; because, according to the natural laws of matter, 1 lb. can never support more or less than 1 lb. We shall presently see how this is to be interpreted.

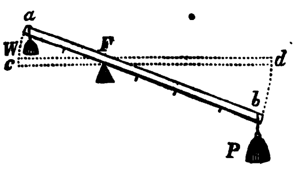
A machine is either at rest, in which case the power simply *supports* or *sustains* the weight or resistance, or the machine is in motion, in which case the power *raises* the weight, or *overcomes* the resistance. When a machine is at rest (in a state of equilibrium), there are always some fixed points or props, amongst which the pressure excited by the weight or power, or the united pressure of both, is distributed. Thus, if the weight is 1000 lbs., it is possible so to distribute it, that any portion of it we please may be supported by the props, and only the remaining part of it, which

can never be greater or smaller than the power itself, is supported by that power; whence it appears, *that the power never supports a greater or less weight than is equal to its own force*, and that the rest of the pressure is sustained by the props and supports of the machine.

EXAMPLES. In the simple and compound lever (Figs. 47—50, and 55), the power and weight are so distributed that the props support the whole pressure of both. In the movable pulley, Fig. 97, on which 1 lb. sustains 2 lbs., or in which the weight is twice the power, half the weight is supported by the tension of the fixed cord, that is, by a part of the machine itself; consequently, after making this deduction, the power is just equal to the weight. In the wheel and axle, the pressure of both power and weight is distributed through the axis of the cylinder which is supported by the machine; and on the inclined plane (to which the wedge and screw are referred), part of the weight is supported by the surface of the plane (§ 90), and only the remainder of the weight is supported by the power.

When the machine is in *motion*, a different principle is involved. In this case, it is easy to prove that the total expenditure of power to raise the weight to a given elevation, is always equal to that which would be expended if the power were directly applied to it, without the intervention of the machine; for it is a universal law of all machinery, that *the velocity of the weight is just as many times less than that of the power, as the power itself is less than the weight.*

Fig. 114.



To understand this, let us at first consider the motion of a lever. (Fig. 114.) Suppose the power, P, is applied at a distance of 4 inches from the fulcrum, and the weight only at a distance of 2 inches. When the lever is moved on the prop, F, the power, P, evidently describes an arc, *bd*, twice as large as the arc *ac*, described by the weight, W; because the radius F*b* is twice as large as the radius *a*F. Hence, in this machine, in which the power is twice the weight, it will also have to move through twice the space through which the weight moves; consequently, what is saved in power is lost in velocity. In the wheel and

axle, the power is to the weight as the radius of the axle is to that of the wheel; but just in the same proportion is the velocity of the weight attached to the axle diminished; and, in the wheel-work, the velocity of the weight is just as many times less than that of the power applied to the first wheel as the weight itself is greater than the power. In the screw, the power is to the resistance as the distance between two adjacent threads is to the circumference of the cylinder; but it is readily perceived that the power must describe a whole circumference to raise the weight only to the distance of two adjacent threads, &c. Hence we may infer generally, that a machine can never *generate a power, or diminish the total expenditure of power, necessary to raise the weight or overcome a given resistance.* All we are enabled to do by machinery *is to expend power at a slow rate, and in directions the most advantageous to the application of the force.*

The principle contained in the preceding section is also contained in what is called *the golden rule of mechanics*, or *the principle of virtual velocities*, viz. *The power multiplied by the space through which it moves in a vertical direction must be equal to the weight multiplied by the space through which it moves in a vertical direction;* that is, the greater the space is through which the power moves, the less need the power itself to be, which is to raise a given weight. This may be illustrated by a very simple example. Suppose the joint weight of 10 distinct pounds was to be raised to the height of 1 foot; if the power employed to raise it is to be expended in one single effort, it must evidently be equal to $1 \times 10 = 10$; but if the power is permitted to make 10 distinct efforts, raising each time 1 lb. of the weight, then the power 1 will have moved through 10 times the space, and the total expenditure will be $10 \times 1 = 10$, as before.*

§ 174. Before concluding this chapter, it will be well to say a few words on the construction of the *balance*—an instrument of the most universal application, both in the arts and sciences. It consists of a two-armed lever

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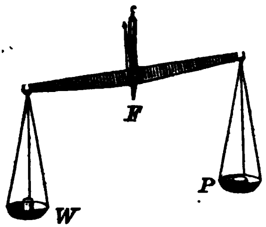
* Setting out from the principle of virtual velocities as an *axiom*, we might establish the law of each simple machine, as found in the preceding sections, by the simple force of mathematical reasoning; but as this would considerably swell the pages of this volume, without materially increasing their practical utility, we refer the learner to the treatises on mechanics.

Fig. 115.



(Fig. 115), in which the fulcrum, F (here called the *axis*), is in the middle, between the two points A and B, from which are suspended the scales, in which the weights are placed. The use of this instrument is sufficiently plain from its construction. When the beam or lever, AB, is in a horizontal position, it indicates an equality in the weights which are compared in the scales.

§ 175. The requisites of a good balance are principally these:—

1. The two arms should be perfectly equal to each other.

2. The axis of the fulcrum should be above, and not far from the centre of gravity, of the beam.

If the fulcrum were in the centre of gravity, the beam, loaded with equal weights, or not at all loaded, would remain at rest in any position; whereas it is intended that an equality between the weights should be indicated by the *horizontal* position of the beam. If the axis were below, or too far above, the centre of gravity, the apparatus might easily be upset, or have too great a tendency to persevere in a horizontal position.

3. The axis, and the points to which the scales are attached, should be in the same straight line.

4. The arms of the lever should be made sufficiently strong not to bend when charged with the weights, and, at the same time, not too heavy; because this would destroy the accuracy of the balance.

5. Frictions at the axis and the points of suspension ought to be avoided as much as possible; wherefore it is best to make the axis and points of suspension of hardened steel, and in the form of a sharp wedge, to diminish the points of contact.

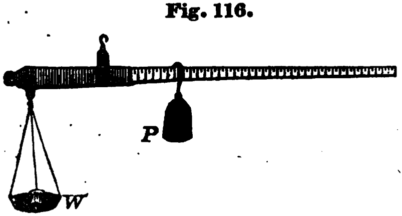
§ 176. The most accurate way of using the balance, is to place the thing whose weight is to be ascertained in one scale, and to balance it by any convenient substance in the

other; then remove the thing, and introduce in its stead as many weights as will again establish the equilibrium of the balance. By this method (which is, of course, not very convenient in practice) all errors arising from the inequalities of the arms, or other imperfections of the balance, are completely obviated. But, whatever precaution we take, the balance is never a *perfect* instrument for determining the weights of bodies. The friction at the axis and the points of suspension is always a hindrance to the motion of the beam, to overcome which the difference between the weights must exceed a certain minimum, before the position of the lever will be changed.

Mr. Ramsden constructed a balance for the Royal Society of London, which, when loaded with 10 lbs., would turn with half a grain, or the ten millionth part of the weight; and Fortin, of Paris, constructed one which, when charged with 4 lbs., is turned by the $\frac{1}{70}$ part of a grain. In all such cases, knowing the degree of accuracy of which the balance is susceptible, we know the extent of the error to which its results may lead us.

§ 177. The common steelyard is another kind of balance, less accurate than the one we have just described, but frequently used for weighing heavy goods. It consists of a two-armed lever; but the fulcrum, or axis, is not in the centre, and divides the beam into two unequal parts, as represented in Fig. 116.

Fig. 116.



In this instrument, instead of placing different weights at the same distance from the fulcrum, the same weight is placed at different distances, to be in equilibrium with the body which is to be weighed; for, according to the law of the lever, the weight of the body will be to the poise, P, in the inverse ratio of their distances from the axis. In this balance, the weight and poise are equal, when they are both at the same distance from the axis: when the poise is twice as far, the weight of the body is twice the poise, and so on. In this manner the longer arm of the steelyard is graduated to facilitate its application in practice.

There are yet other instruments for determining the weight and specific gravities of bodies, some of which we shall become acquainted with in the next chapter; and, for the rest, we must refer the student to the Introduction of our Elements of Chemistry.

RECAPITULATION

OF THE MOST IMPORTANT PRINCIPLES CONTAINED IN CHAPTER IV.

[§ 150.] To what may all simple machines, together with their compounds, be reduced?

Of the Pulley.

[§ 151.] What do you call a pulley? What do you call a fixed pulley? In what directions are the power and weight applied to the wheel of the machine? What is the proportion between the power and weight of this machine? Why? (Explain Fig. 94.) What advantage, then, is gained by this machine? Explain Fig. 95.*

[§ 152.] When is a machine called a *movable* pulley? (Explain Fig. 97.) If the directions of the ropes, in this arrangement, are all parallel to each other, by what is the whole weight sustained? What follows, in this case, from the tensions of both parts of the rope being equal? *What proportion, therefore, exists in this arrangement between the power and the weight?*

[§ 153.] If the directions of the cords AB, DE, are not parallel, but inclined to each other by any angle you please, by what rule can you then determine the relation of the power to the weight? (Explain Fig. 98.) What is the ra-

* Can you explain the law of the pulley mathematically? (Explain Fig. 96.) What is the general expression of the ratio of the weight to the power of *n* movable pulleys?

tio of the power to the weight in such a machine?* *What must the weight in this arrangement be always less than?* Why?

[§ 154.] By what means may the mechanical power of the pulley be increased? What is such arrangement called? (Explain Fig. 100.) How does, in this system, the power of one weight act upon the other? What, therefore, is the relation of the weight to the power in the arrangement represented in the figure?

Why? What would be the relation of the weight to the power, if there were 4 movable pulleys? What, if there were 5?†

[§ 155.] Can a single rope be so arranged by a movable pulley, that the power supports three times the weight? Explain Fig. 101.

How is the same power produced by the arrangement represented in Fig. 102? How is a system of pulleys, for the sake of compactness, often arranged? *What is the relation of the weights to the power, when several sets of pulleys are employed?* Suppose two sets only were employed, the weight of the one being 10 times the power, and, in the other, 5 times the power, what would be the proportion between weight and power of the whole machine?

[§ 156.] By what are the mechanical effects derived from a system of pulleys, diminished in practice? To what do these hindrances often amount? What are the principal uses of the pulley?

Of the Wheel and Axle.

[§ 157.] What do the wheel and axle consist of? (Explain Fig. 104.) What may be used instead of the wheel? What is the machine called, if the cylinder be provided with a winch?

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* Can you prove, mathematically, *that the tension of either part of the rope is to the weight at the centre, as the radius of the pulley is to the chord embraced by the arc?* What change does this formula undergo, when the directions of the rope are parallel to each other? With what does this rule agree?

† Can you express this law mathematically?

§ 158.] What is the machine called, when the axis of the machine is vertical? For what purposes is it then used?

[§ 159.] To what simple machine may the wheel and axle be reduced? *What, therefore, is the ratio of the power to the weight?* What would be the ratio of the power to the weight, if the radius of the wheel were 5 times that of the axle? What, if it were 10 times that of the axle?

Does it make any difference whether the power is applied immediately to the circumference of the wheel, or to the spokes, or to the winch?

[§ 160.] Can you *in practice* diminish, at pleasure, the diameter of the axle, or increase that of the wheel? Why not? How are these inconveniences partly remedied? (Explain Fig. 107.) Explain the operation of this arrangement. *What need the power*, P, *multiplied by the radius of the wheel or winch, only be equal to? To what, therefore, is this arrangement equivalent?*

[§ 161.] What are the uses of the wheel and axle? Wherein consists its greatest advantage? What, therefore, has it been called? What is a common lever used for? Where must the wheel and axle be employed?

[§ 162.] How may the wheel and axle be combined with each other? Explain the arrangement represented in Fig. 108. In what proportion is the united power of this arrangement to the weight? Supposing there are 5 wheels employed, and the radius of each wheel is 4 times that of the axle, what is the ratio of the power to the weight? What, if 10 such wheels were employed?

What is necessary in order that the wheels and pinions of such a combination of wheels shall work together? What follows from this?

[§ 163.] In what proportion are the velocities of the pinions and wheels? Why? Give an example.

Of the Wedge.

[§ 164.] What is the wedge an application of? How is it constructed and used? Explain Fig. 109.

[§ 165.] Is the power of the wedge as easily computed as that of other simple machines? Why not?

What other difficulties are yet in the way of the computation of the power of the wedge? *

[§ 166.] What instruments or tools in the mechanic arts are referable to the theory of the wedge? *How is the power of the wedge, in all these cases, increased?* Is there no limit to this?

How does a nail, driven into a piece of wood, or into a wall, act? By what is it afterwards retained? How does a saw act?

Of the Screw.

[§ 167.] What does a screw consist of? What are the two principal parts of the screw? How are they formed? In how many different ways is this machine used? With what is either of these arrangements combined?

[§ 168.] In what manner may you consider the thread of a screw formed? What law, therefore, applies to the screw? *What is the ratio of the power to the resistance of the screw?*

[§ 169.] To what does this ratio of the power to the resistance of the screw only apply? How many times less may the power be, when it is applied by means of a lever? And as this lever, when the screw is used, describes the circumference of a circle, what will be the *combined ratio of the power of this arrangement to the weight?* In what ratio, therefore, does the power increase in the same screw? In what ratio does it increase upon different screws, the power being applied at the same distance? †

[§ 170.] In what cases is the screw principally employed? For what other purposes is it used?

[§ 171.] With what other machine may the screw be advantageously combined? Describe this arrangement. (Fig. 113.) What do you call such an arrangement? How is its power calculated?

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* If you abstract from friction, what relation subsists, mathematically, between the power applied to the back, and the forces exerted against the sides of the wedge?

† If p stands for the power, r for the resistance, D for the distance at which the power is applied from the axis, h for the distance between two adjacent threads, and 2π for the circumference of a circle, whose radius is 1, how can you express the relation between the power and resistance of the screw mathematically?

What is the ratio of the power of the whole machine to the weight? Suppose the distance between two adjacent threads is 4 inches, the length of the winch 24 inches, the radius of the wheel 30 inches, and that of the axle 5 inches; what would be the ratio of the power to the weight of this machine?

[§ 172.] What are the five simple machines,—the lever, the inclined plane, the pulley, wheel and axle, wedge and screw,—called? Why? Give instances.

[§ 173.] When a machine is at rest, how is the pressure excited by the power and weight always distributed? Give an instance. *How large a weight, therefore, does the power in all cases support?*

How are the power and weight distributed on the simple or compound lever? How much of the weight on the movable pulley is supported by the tension of the fixed cord? What portion of the weight, therefore, does the power support? How is the pressure of the power and weight distributed on the wheel and axle? How, on the inclined plane?

What principle can you prove in reference to a machine which is in motion? *What universal law subsists in reference to all machinery?*

How can you prove that this law holds true of the lever?

Explain Fig. 114. How does it apply to the wheel and axle? How to the screw? *What general inference can we draw from this?*

In what consists the principle of virtual velocities? How can you illustrate this principle by an example?

[§ 174.] What are the principal parts of a balance?

[§ 175.] What are the principal requisites of a good balance?

[§ 176.] What is the most accurate way of using the balance? Is the balance a *perfect* instrument for ascertaining the weights of bodies? Why not?

[§ 177.] Of what does the common steelyard consist? How is this instrument used? When are the weight and poise, in this balance, equal to one another? When is the weight twice the poise? When three times? &c.

CHAPTER V.

LAWS OF MOTION OF FLUIDS.

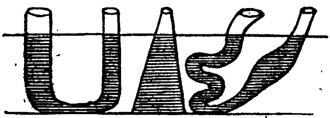
A.—PRESSURE, WEIGHT, AND EQUILIBRIUM OF LIQUIDS.

(*Hydrostatics.*)

§ 178. *Fundamental Law.—A liquid in a vessel cannot rest, until its surface is perfectly horizontal and level.* For, if any part of the fluid is placed higher than the rest, and then left to itself, it will, on account of the extreme mobility of its particles, descend as on an inclined plane, and thereby raise the lower parts, until its surface is perfectly even.

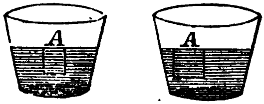
§ 179. *Water, or any other liquid which communicates with water, or the same liquid, by means of canals, tubes, or pipes, stands equally high in both places.* Thus, water stands equally high in the two legs of a siphon. (See the figure.)

Fig. 117.



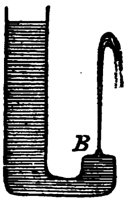
This may be shown by experiments, and explained in this way: When the surface of a liquid is once horizontal, every part of it must be at rest. Now, if the part A, for instance, is taken away, the neighboring part must flow in its place. This, however, is rendered impossible, if some hard, impenetrable body, of the same bulk and shape, is substituted for it. The remaining liquid will then continue in its horizontal position. And it makes no difference whether A is in the middle of the basin (as in one of the figures), or on one of its sides (as in the other), or if there are three, four, and more places, in which, instead of the liquid, *a solid hindrance is placed, to prevent the confluence of the liquid.*

Fig. 118.



§ 180. If one of the legs of a siphon is shorter than the other, and provided with an orifice in B, then the liquid sallies forth from this orifice; and if the stream is directed perpendicularly upwards, it is thrown nearly as high as the surface of the liquid in the other leg.

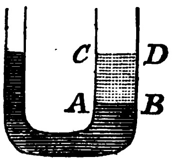
Fig. 119.



The reason why, in reality, it does not reach the same height as the surface of the liquid in the other leg, is because the resistance of the atmosphere and the friction of the orifice impede its velocity.

§ 181. If, instead of providing an orifice, it is closed with a horizontal plane, AB, then the pressure of the liquid upon that plane (upwards) is equal to the column ABCD of the liquid, which, when placed upon AB, establishes the equilibrium.

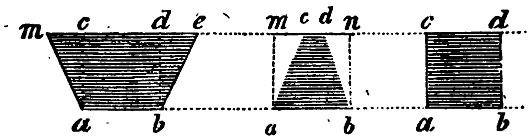
Fig. 120.



Thus, if AB is closed with a bladder, it is necessary to place upon it as much weight as is equal to the column ABCD, which would be in equilibrium in the other leg. This may be shown by experiments. A small quantity of water in one leg can thus exercise an enormous pressure upon a horizontal surface, AB. This pressure has been taken advantage of in the construction of Count Real's filtering press, and in Brahma's hydraulic press, for the description of which we refer the student to our treatise on Chemistry—(*Chemical Apparatus.*)

§ 182. *The pressure of water, or any other liquid,* UPON THE BOTTOM *of a vessel, is equal to the weight of a per-*

Fig. 121.

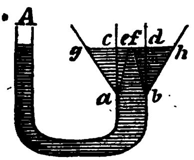


pendicular column, a b c d, of the same liquid, which has for its basis the bottom of the vessel. It is, therefore, less than the weight of the whole liquid, if the vessel grows wider near

the top; greater than the weight of the whole liquid, when the vessel grows narrower near the top; and equal to the whole weight of the liquid, when the vessel is throughout of the same diameter. Thus the pressure upon the bottom of each of the three vessels represented in Fig. 121, is the same, if the bottoms of these vessels are equal, and the liquid stands equally high in all.

This law takes its origin in the disposition of all fluids to expand themselves horizontally in all directions. For it has been said before (§ 179), and it can be proved also by experiments, that the liquid must stand equally high in both legs of two communicating tubes (Fig. 122), *whatever be their shape;* consequently, it makes no difference whether one of the legs grows narrower or wider at the top; that is, whether the shape of the tube is *agbh* or *abef*. In both cases, the liquid rises as high in one leg as in the other; which proves that the pressure upon the plane *ab* is always the same; namely, equal to the perpendicular column *abcd*, which of itself would be in equilibrium with the liquid in the other leg.

Fig. 122.



§ 183. *Lateral Pressure of Liquids.* From what has gone before, it follows, *that the pressure upon any point in the side of a vessel, depends upon the height of the liquid above that point.* The deeper, therefore, this point is situated under the surface of water, the greater is the pressure upon it. Moreover, it may be mathematically proved, that *the velocity with which the water spouts from different orifices in the sides of a vessel, is proportional to the square root of the perpendicular distance of that point from the surface of the liquid in the vessel.*

Upon this lateral pressure depends the reaction of water on pipes through which it flows. If a suspended vessel be provided with several such pipes, it will turn in the opposite direction to that in which the water runs out by the pipes.

§ 184. Liquids of different specific gravities (see § 24, page 23) do not stand equally high in communicating vessels or tubes; but the specific heavier will stand as many times lower than the other, as its specific gravity is greater than that of the liquid in the other tube.

This may be proved by experiments, and is sufficiently evident

from the law given in § 181, page 162. If the two liquids are quicksilver and water, the water will stand nearly 14 times higher than the quicksilver.

§ 185. When the surface of a liquid in a vessel is perfectly horizontal, then every portion of it is kept in its place, or held up by the pressure of the surrounding parts. The same pressure is exercised upon any solid body immersed in it, which is therefore held or pressed upwards with the same force as an equal portion of the liquid. From this we derive the following general law: *A body immersed in water, or in any other fluid, loses as much weight as an equal bulk of the fluid weighs; and the fluid gains the same weight.*

§ 186. According to this law, a body immersed in a liquid of the same specific gravity must rest in the place where it is put. But a body of greater specific gravity will sink, and one of less specific gravity will rise to the top, and float.

In the first case, it loses all its weight, and, its pressure downwards being every where the same as that of an equal portion of the liquid, there is no power, either upwards or downwards, to put the body out of its place. In the second case, the pressure downwards is greater than the pressure of the liquid upwards; therefore the body must follow the impulse of the greater force, and sink. Finally, in the third case, the pressure of the liquid upward is greater; consequently, the body must rise, and float.*

§ 187. The law just given, with regard to solid bodies, applies equally to liquids of different specific gravities. Thus, if several fluids (which have no chemical affinity† for each other) be poured together in the same vessel, the specific heaviest will descend to the bottom, and the specific lightest will rise to the top.

It sometimes happens that a specific heavier body rests on the surface of a lighter fluid. But this takes place only,

1st. When the lower fluid can no where give way to the upper fluid, and at the same time the sides of the vessel are strong enough to resist their united pressure;

2d. When the pressure of the upper fluid is in every point the same, because in this case no point can yield.

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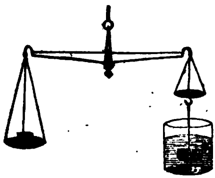
* The weight of the immersed body is always $= G - g$, where G is the absolute weight of the body, and g the weight of an equal bulk of the liquid.

† See § 44, page 40.

APPLICATION OF THE FOREGOING LAWS TO THE DETERMINATION OF THE SPECIFIC GRAVITIES OF BODIES.

§ 188. For the purpose of ascertaining the specific gravities of bodies, we make use of an instrument called the *hydrostatic balance,* whose difference from a common balance consists chiefly in one of its scales being shorter than the other (see the figure), and provided with a hook, by which the heavy body which is to be weighed is suspended. The body is first weighed out of water; then it is immersed, and its loss of weight ascertained, which (according to § 185) is the weight of an equal bulk of the fluid. If the specific gravity of distilled water is taken for unity of measure, then we need only *divide the absolute weight of the body by its loss, when immersed in distilled water; the answer will be the specific gravity of the body.*

Fig. 123.



§ 189. The principal cases that can occur in the determination of specific gravities, are the following:—

1st CASE. *When the body is heavier than water. Weigh it first out of water, then ascertain its loss in water, and divide the one by the other; the answer is the specific gravity of the body.*

EXAMPLE. Let the body weigh 3 lbs. out of water, its loss in water 2 lbs.; then its specific gravity is $\frac{3}{2} = 1.5$.

2d CASE. *When a body is lighter than water. Annex to it a piece of a heavier body, whose weight and loss in water have been previously ascertained; so that it will sink. From the loss of the compounded mass subtract the loss of the heavy body alone; the difference is the loss of the body whose specific gravity is to be ascertained. Its absolute weight, divided by this loss, will then be its specific gravity.*

EXAMPLE. Suppose a piece of elm weighs 15 lbs. out of water, and a piece of copper, which weighs 18 lbs., loses 2 lbs. when immersed in water; let the compound mass lose 27 lbs.; then 27 less $2 = 25$, is the loss of the elm alone,

which, divided into the absolute weight of 15 lbs., gives $\frac{15}{25} = \frac{3}{5}$, or 0.6, for the specific gravity of elm.

3d CASE. *For a fluid. Find the loss of weight of one and the same body in water, and in the fluid whose specific gravity is to be ascertained; divide the loss in the fluid by that in water: the answer is the specific gravity of the fluid.*

EXAMPLE. Suppose a piece of iron * loses in distilled water $\frac{5}{37}$ lbs. and in sea-water $\frac{5}{36}$ lbs.; then the specific gravity of sea-water is $\frac{5}{36}$ divided by $\frac{5}{37}, = \frac{37}{36} = 1.03$ nearly.

Other means also are employed for the determination of the specific gravity of fluids; the most important of which are described in Chemistry, under the head of *Chemical Apparatus.*

§ 190. *Floating and Immersing of Bodies.* Bodies, whose specific gravities are less than that of water, must float on its surface, or immerse only as far as will make the weight of the whole body equal to the weight of a bulk of water of the magnitude and shape of the immersed part. If such a body is forced down deeper, and let free, it will rise again to the same height.

This may be shown by numerous experiments on woods, and other substances; the heavier they are, the deeper do they immerse; but if a piece of light wood be forced down into the water, and then left free, it will immediately rise again to the surface.

§ 191. *Wine and Beer Scales.* It follows from what we have said, that the same body cannot be equally deep immersed in liquids of different specific gravities, and that it will immerse *deepest* in the specific *lightest* fluid. Upon this principle is founded the construction of wine, beer, and brandy scales; the construction of Nicholson's aërometer, &c.; all which are described in the Introduction to Chemistry.

§ 192. *Swimming.* Bodies of greater specific gravities than water, can be made to float, by making them hollow, or compounding them with lighter substances, so that the weight of an equal volume of water is still greater than that of the compound mass.

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* For this purpose, a piece of glass is generally used; particularly in ascertaining the specific gravity of acids, which affect metals chemically.

Hereupon is founded the floating of empty bottles, of vessels, &c.; the rising of balloons filled with a lighter fluid than air, &c.; swimming by means of bladders, &c.

The specific gravity of the human body averages 1.12. There are, however, men whose specific gravity is less than water. These are natural swimmers. Very fat men are generally good swimmers; because, by displacing a greater quantity of water, they lose more of their own weight.

§ 193. *Position of a Floating Body.* The position of a floating body depends on its centre of gravity, and on the centre of gravity of the bulk of water which is displaced by the immersed part of the body. Both centres of gravity must lie in the same vertical line; otherwise the body cannot remain in its position. The deeper the body is immersed, the safer is it from turning over. In general, the centre of gravity of a swimming body ought at least to be under the surface of the water.*

§ 194. *Absolute Weight of a Cubic Foot of Water.* When the weight of a cubic inch or foot of distilled water is known, *we can find the absolute weight of a cubic foot of any substance, by multiplying the specific gravity of that substance by the weight of a cubic foot of distilled water.*

Hutton, in his course of Mathematics, makes a cubic foot of water equal to 1000 ounces avoirdupois weight. This, however, disagrees somewhat with the statements of others. In the same manner do the specific gravities in his table disagree with those formed by some of the best chemists. Lavoisier and Brisson† found a cubic foot of rain water equal to 70 lbs. Paris weight. (See the table of specific gravities at the end of the book.)

B.—PRESSURE, WEIGHT, AND EQUILIBRIUM OF ELASTIC FLUIDS.

(*Aërostatics.*)

§ 195. *Fundamental Law.—When an elastic fluid is shut up in a vessel, it will press its sides equally in all direc-*

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* Benjamin Franklin's Letters on Philosophical Subjects. London, 1769. Euler's Naval Science. Petersburgh, 1749.

† Pésanteur specifique des Corps, utile à l'Histoire Naturelle, &c. Par Brisson. Paris, 1787.

tions, with a force proportional to the elasticity of the enclosed fluid.

§ 196. If the sides of the vessel are not strong enough to resist this pressure, then the fluid will burst through them; or, if the vessel be provided with an orifice, the fluid will pass through it, until its expansive power is exhausted.

§ 197. An elastic fluid cannot escape from a vessel, when the elasticity, and consequently the pressure, of an elastic fluid without, is equal to the pressure of the fluid within the vessel. If the pressure of the elastic fluid without is greater than that of the elastic fluid within, and the vessel is provided with an orifice, then the fluid from without will enter the vessel; or, if the pressure of the inner fluid is greatest, it will escape through the orifice, until the elasticities of both fluids are in equilibrium.

§ 198. *Compressibility of Elastic Fluids.* Every elastic fluid can, by pressure, be forced into a smaller bulk. Its elasticity and density are then found to increase in proportion to the force or weight which compresses it. (See the experiment described, § 10, page 17.) The elasticity and density of elastic fluids are also increased by compressing greater quantities of them in the same space. Both modes of compression must have their limits, when the fluid has reached its greatest density.*

§ 199. The degree to which an elastic fluid may be compressed, varies. Some of them lose, by great pressure, their elastic form, and become liquid; others are *permanently elastic*, at least as far as our experience goes, by the greatest pressure until now applied to them.

Probably all elastic fluids would become liquid, if it were possible to compress them sufficiently for this purpose.

§ 200. *Absolute and Specific Elasticity of Fluids.* We distinguish also between *absolute* and *specific* elasticity of fluids. By *absolute* elasticity we mean the degree with which it resists pressure or compression; by *specific* elasticity we understand the degree with which an elastic fluid,

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* Tobias Mayer's Nat. Phil. page 197.

of the same density, resists pressure. Thus, of two elastic fluids, which resist pressure with the same force, the specific elasticity of the thinner fluid is the greater. Fluids of the most different *specific* elasticities, may yet have the same *absolute* elasticity, and therefore be in equilibrium with each other.

§ 201. *Formation of Atmospheres.* When an elastic fluid is attracted by a solid or liquid body, it must form around it an *atmosphere*, whose density will be greater near the body than farther from it; because the layers which are next to the body are pressed by the gravitation of those above them. Every body in nature may, in this manner, be surrounded by an atmosphere.

§ 202. *Equilibrium of Elastic Fluids.* When such an atmosphere is in the state of rest, then every part of it is, by its elasticity, in equilibrium with the pressure of the gravitating parts above. It will, therefore, neither give way to that pressure, nor cause any motion in the surrounding particles.

§ 203. *Motion of Elastic Fluids—Winds, &c.* But if, by some mechanical or chemical cause, either the elasticity or the density of the layers, or even the pressure of the surrounding particles, is changed, then a motion of the fluid, or at least of a portion of it, must necessarily take place, and continue until the conditions of its equilibrium (§ 197, page 168) are again established.

Upon this principle depends the whole theory of winds and currents.

§ 204. *All elastic fluids are expanded by heat, and compressed by cold.* In the first case, they exercise, with much less density, the same pressure as before with greater density. Thus, *heat increases the specific gravity of elastic fluids.*

This we know from experience; the power of steam, for instance, increases with the heat. In a closed, warm room, the pressure of air often becomes insufferable, when we may expose ourselves to the same, or even a greater degree of heat, without suffering any inconvenience from it, when there is a draft or an aperture for the inner air to pass through, and establish the equilibrium with the air without. A bladder filled with air, will burst when exposed to heat, &c.

§ 205. When two or more elastic fluids are placed upon one another, the specific heaviest will descend, and the specific lightest will rise to the top. In such cases, the laws of hydrostatics (§ 178, 179, page 161) apply to elastic fluids.

RECAPITULATION.

LAWS OF MOTION OF FLUIDS.

A.—*Pressure, Weight, and Equilibrium of Liquids.*

(*Hydrostatics.*)

[§ 178.] *Can you tell me the fundamental law of hydrostatics?* How can you convince me of its correctness?

[§ 179.] *What law is there with regard to water, or any other liquid, which communicates with water or the same liquid?*

How can you explain this principle?

[§ 180.] What takes place when a filled siphon has one of its legs shorter than the other, and provided with an orifice?

What is the reason that the liquid which sallies forth from the orifice of the shorter leg, does not reach the same height as the surface of the liquid in the other leg?

[§ 181.] If, instead of being provided with an orifice, the shorter leg of the siphon is closed with a horizontal plane, what will the pressure upon that plane (upwards) be equal to?

If the shorter end be closed with a bladder, how much weight must be placed upon it, to be in equilibrium with the liquid in the other leg? What are we, by this law, enabled to produce?

[§ 182.] *What is the pressure of water, or any other liquid, upon the bottom of a vessel, equal to?* When is this pressure less than the weight of the whole liquid? When, greater than the weight of the whole liquid? When is it equal to the weight of the whole liquid?

In what does this law take its origin? How can you explain it?

[§ 183.] *Upon what does the pressure upon any point in the side of a vessel depend?* What law exists with regard to the velocity with which water spouts from different orifices made in the sides of a vessel?

What depends on this lateral pressure? What phenomena are explained by it?

[§ 184.] Do liquids of different specific gravities stand equally high in communicating vessels, or tubes? What law, then, is there for such liquids?

If the two liquids are water and quicksilver, how much higher will the water stand than the quicksilver?

[§ 185.] When the surface of a liquid in a vessel is perfectly horizontal, how is every portion of it held up, or kept in its place? What pressure does a liquid exercise upon a solid body immersed in it? *What general law is derived from it?*

[§ 186.] How does the law you have just named apply to a body which is immersed in a liquid of the same specific gravity? How does it apply to a body whose specific gravity is greater than that of the liquid? How, to a body whose specific gravity is less than that of the liquid?

How can you explain these three cases?

[§ 187.] Does the law you have just given for solid bodies, apply also to liquids of different specific gravities? What takes place if several fluids which have no chemical affinity for each other, be poured together in the same vessel?

Is this rule without exception? What are the cases which are exempt from it?

Application of the foregoing Laws to the Determination of the Specific Gravities of Bodies.

[§ 188.] What is the name of the instrument which is used for the determination of the specific gravities of bodies? What does it consist of? How is it used? If the specific gravity of distilled water is taken for unity of measure, *how*

is the specific gravity of a body found, when its absolute weight, and its loss in distilled water, are known?

[§ 189.] Which are the principal cases that can occur in the determination of specific gravities? *How do you find the specific gravity of the body in the first case? How in the second? How in the third?* If, in the first case, the body weighs 3 lbs. out of water, and its loss in water is 2 lbs., what is its specific gravity? Again, if, in the second case, a piece of wood weighs 15 lbs. out of water, and a piece of copper weighing 18 lbs. loses 2 lbs. when immersed; if, further, the compound mass of copper and wood loses 27 lbs. in water, what is the specific gravity of the wood? Finally, if a piece of iron loses in distilled water $\frac{5}{37}$ lb., and in sea-water $\frac{5}{36}$, what is the specific gravity of the sea-water? *

[§ 190.] To what depth can a body, whose specific gravity is less than that of water, be immersed? What takes place when it is forced down deeper, and then left to itself again?

[§ 191.] Can the same body be immersed equally deep in liquids of different specific gravities? In what fluid will it be immersed deepest?

What instruments are constructed on this principle?

[§ 192.] How can bodies of greater specific gravity than water, be made to float?

What phenomena are explained by this principle? What is the average specific gravity of the human body? Why are fat men naturally good swimmers?

[§ 193.] On what does the position of a floating body depend? What is necessary in order that the body shall remain in its position? What must be the position of a floating body, in order to secure it from turning over? What position should the centre of gravity of a swimming body have with regard to the surface of the water?

[§ 194.] *When the weight of a cubic inch or foot of distilled water is known, how can you find the absolute weight*

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* The teacher may now give as many more examples as he may think fit, or serviceable to his pupils.

of a cubic foot of any substance, when its specific gravity is known? *

B.—*Pressure, Weight, and Equilibrium of Elastic Fluids.*

(*Aërostatics.*)

[§ 195.] What is the fundamental law for an elastic fluid shut up in a vessel?

[§ 196.] What will take place if the sides of the vessel are not strong enough to resist the pressure of the fluid within?

[§ 197.] Can an elastic fluid escape from a vessel, when the pressure of an elastic fluid without is equal to that of the fluid within? What will take place if the pressure of the elastic fluid without is greater than that of the fluid within, and the vessel is provided with an orifice? What, if the pressure of the inner fluid is greatest?

[§ 198.] What can every elastic fluid by pressure be forced into? In what ratio do the density and elasticity then increase? Is there no other means of increasing the elasticity and density of a fluid? What is it?

[§ 199.] Is the degree to which elastic fluids may be compressed, the same in all fluids? What changes do some of them undergo, when compressed? What are those fluids called, which, even during the greatest pressure applied to them, retain their elastic form?

Is it probable all elastic fluids may become liquid by pressure?

[§ 200.] What do you understand by absolute and specific elasticity of fluids? Can fluids of different specific elasticities be in equilibrium with each other? When does this take place?

[§ 201.] When an elastic fluid is attracted by a liquid or solid body, what does it form? Why must the density

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* The teacher may give his pupils some examples from the table of specific gravities, at the end of the volume.

of the atmosphere be greater near the attracting body, than farther from it?

[§ 202.] When an atmosphere is in the state of rest, how is every particle of it kept in its place?*

[§ 203.] But what must take place, when, by some cause or other, either the elasticity or density of the layers, or even the pressure of the surrounding particles, is changed?

What do you call this motion, when occurring in our own atmosphere?† and what phenomena does it explain?

[§ 204.] *How does heat affect all elastic fluids?* How does heat affect the specific elasticity of fluids?

Give examples of such effects produced by heat.

[§ 205.] When two or more elastic fluids are placed upon one another, what respective positions will they take? What laws apply here?

[The teacher may here ask his pupils to repeat the laws of hydrostatics.]

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* By its own elasticity, which is in equilibrium with the gravitating particles above.

† *Ans*. This motion is then called *wind;* which, according to the direction in which it moves, is called *north* or *south*, *west* or *east* wind. The whirlwind is caused by two currents of air moving in opposite directions.

CHAPTER VI.

MECHANICAL PROPERTIES OF THE ATMOSPHERE.

§ 206. *Existence of Atmospheric Air.* Our earth is every where surrounded by a thin, invisible fluid, which is termed the *atmosphere* (§ 201), of whose existence every day's experience furnishes sufficient proof.

Here the teacher may give some examples. The rapid motion of the hand produces wind; a tumbler, or a bottle, with the bottom uppermost, held perpendicularly under water, is only partly filled, but when held obliquely, air departs from it in bubbles. The same is the case with a diving-bell, &c.

§ 207. *Height of the Atmosphere.* The height of the atmosphere above the surface of the earth is not yet exactly ascertained; but it is found at the top of the highest mountains, and it is evident from calculation (of its pressure), that it must extend many miles above them.

§ 208. *Elasticity of Air.* Air is an *elastic fluid;* because it is compressible, and expands itself again, when left free, to its original volume.

This may be shown by experiments. In a hollow cylinder closed at one end, the air may be compressed by a piston; but as soon as the piston is left to itself, the air in the cylinder will push it back again. (See the experiment described in § 11, page 18.) When a bladder is filled with air, it will be susceptible of changing its shape by the least pressure; but it immediately reëstablishes its shape, when the pressure is removed.

§ 209. *Air is a heavy fluid, and, as such, obeys the laws of gravity.* (§ 71 and 72, pages 57 and 58.)

Fig. 124.

To show this by an experiment, take a tube, AB (Fig. 124), closed at the end A, and, after having filled it with quicksilver, invert it, so that the under end may be unsupported. The quicksilver will not run out, because the *pressure* of the air, acting at B, in opposition to the quicksilver, supports it in the tube. If an aperture be made in A, the quicksilver immediately descends; the air which is admitted by the new aperture then acts equally from above; which shows that when the tube was close at top, it was the external air which supported the quicksilver.

The ancients, to whom this property of air was unknown, explained this phenomenon by the horror which they supposed nature had against empty space (*horror vacui.*)*

§ 210. When the closed tube, AB, is three or four feet long, then part of the quicksilver will indeed run from the aperture B, but the tube will always remain filled to the height of about 28 inches. Hence we infer, *that the pressure of the atmosphere upon a surface, is equal to the weight of a quicksilver-column of 28 inches, having that surface for its basis.*

The space AC, between the quicksilver and the end of the tube, is a real vacuum, which, from its author, Torricelli, is termed *Torricelli's Vacuum.*†

§ 211. If, instead of quicksilver, the tube is filled with water, then the pressure of the air will support a column of nearly 14 times the length of that of quicksilver; which agrees perfectly with the hydrostatic law given in § 184, page 163.

Thus the height of a column of water is $14 \times 28 = 392$ inches, or about 33 feet. This experiment has actually been made by Mr. Sturm, in Germany, with a tube of that height.

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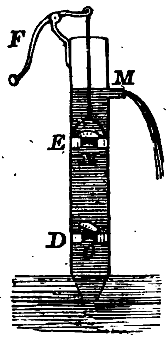
* Euler's Letters to a German Princess, translated by Hunter. London, 1802. Vol. I.

† Torricelli, a pupil of Galileo, first made this experiment in 1643.

§ 212. The above-described property of the air explains the phenomenon of the sucking pump. This consists chiefly of a hollow cylinder, and a piston or sucker, E, fixed to a rod, which is moved up and down by the lever, F. The piston is made hollow, or is perforated in E, and provided with a valve opening upwards. A plug is fixed in the lower part of the barrel, also perforated and provided with a valve opening upwards. When the piston descends, the air which is contained between E and D opens the valve N, and escapes into the barrel above the piston; then, when the piston is raised again, the external atmosphere keeps the valve N shut, and the air in the barrel, being thus exhausted, is no longer in equilibrium with the pressure of the outer air on the surface of the water in the well. This is, therefore, forced up, and through the valve O enters the barrel of the pump. When the piston is pushed down again into the water, which is now in the barrel between E and D, the valve N will be opened by this water, which will now come to stand above the piston; and by the next motion upwards it must flow from the pipe, M. A number of other phenomena are equally well explained by the pressure of the atmosphere.

Fig. 125.



To these belong sucking, drinking, smoking, the use of bung-holes in casks, &c.

§ 213. From the elasticity and gravity of atmospheric air, it follows, that its pressure near the surface of the earth must be greater than farther from it, and, in general, that its pressure decreases in proportion as we ascend. (See § 201, page 169.)

This is proved, also, by the height of a column of quicksilver, which the pressure of air supports in a tube; for the quicksilver in the Torricellian tube stands lower at the top of a high mountain than at its foot. It is also evident that the pressure of air, in a room which communicates with the atmosphere, must be the same as that of the open air; because the elasticity of the air in the room must be in equilibrium with that of the air without. (§ 197.)

§ 214. *Expansion of Air by Heat.* We know, from experience, that air is expanded by heat, and contracted again by cold. If, therefore, it be shut up in a vessel, so as to be unable to expand itself, it will press against the sides of the vessel more than before: if the vessel has an aperture, the heated air will pass through it, until the remaining part of it is in equilibrium with the denser air without.

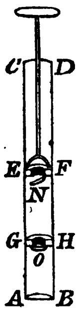
In this manner nearly all the air can be expelled from a vessel; but, as soon as the vessel grows cold, the air will again rush into it; or, if the aperture of the vessel be immersed in water, the water will be forced up into the vacuum.

§ 215. Air which is expanded by heat, must rise above the denser, and consequently specific heavier air, which surrounds it. This is evident from hydrostatic principles. (§ 187.)

This explains the draft in grates, and stoves, and astral lamps; the wind which generally accompanies conflagrations; the rising of a balloon filled with heated air, &c.

§ 216. It has been stated (§ 198), that all elastic fluids, and, consequently, also, atmospheric air, may be compressed by forcing a greater bulk into the same space. This is done by the condensing machine.

Fig. 126.

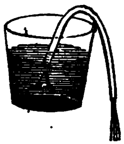


This consists principally of a cylinder made of metal, ABCD (see the figure), provided at O with a valve opening inwards. The piston is also provided with a valve opening inwards. When the piston is moved down, the pressure of the air between E and G shuts the valve N, while the compressed air enters the valve O, in the cavity ABGH. When the piston recedes, the pressure of the air in the cavity ABGH shuts the valve O, so that there remains a vacuum between E and G, to fill which the air without enters through N. As soon as the cavity EFGH is filled with air, the piston is moved down again, and a new portion of air forced through the valve O; and so may the condensation be carried on as long as the sides of the cylinder are strong enough to resist the pressure of the compressed air in the cavity ABGH; and we shall always find, that *the density of the compressed air increases in proportion to the force of the compressing power.*

Upon the compressibility of air depends the theory of the air-gun—which it will now be easy for the teacher to show or explain to his pupils.

§ 217. *Siphon.* Another remarkable and useful experiment, which may be equally well explained from the pressure of the atmosphere, is that of the siphon, which is a bent tube, having its two legs either of equal or unequal length. If it is filled with water, and then inverted, with the two open ends downwards, and held level in this position, the water will remain suspended in it when the legs are equal; but if these be unequal, or the siphon is inclined, so that the orifice of the one end is lower than that of the other, then the equilibrium will be destroyed, and the water will descend by the lower end, and rise in the higher.

Fig. 127.

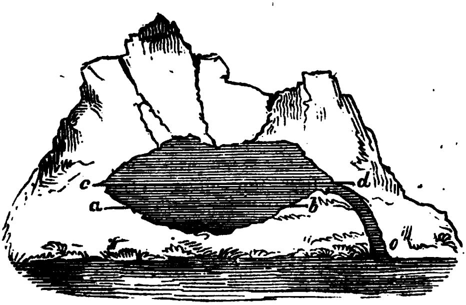


For, in the first case, if the legs are not over 33 or 34 feet high, the pressure of the atmosphere is a counterpoise to that of the water in the legs. (§ 211, page 176.) In the second case, if one of the legs be longer than the other, the air presses equally on both orifices; but, the weight of water in the two legs being unequal, a motion must take place where the power is greatest, and continue till the water has run out by the lower end.

If the shorter leg is immersed in a basin of water, and the water be set a running from the longer leg, which may be done by suction, then the water in the basin is, by the pressure of the air, forced up into the siphon, and continues to run out of the longer leg, until the surface in the basin is at a level with the orifice of the other leg. The whole basin may thus be drained, by making the leg B sufficiently long for the orifice to be below the bottom of the basin.

The theory of the siphon explains some of the most remarkable phenomena in nature. Among them we will mention the

Fig. 128.

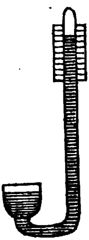


conducting of water over steep hills; the drying of pumps after a heavy rain; and, above all, the remarkable phenomenon of the Lake of Cirknitz, in Karinthia. This lake is sometimes entirely drained, and then filled again. The canal in the province of Languedoc, in France, is founded upon the theory of the siphon.

Suppose the water of such a lake were only as high as the line *ab* (Fig. 128); then it would, of course, remain in its basin; but when risen to the line *cd*, the communicating tube, *do*, must act as a siphon, and the water will be wholly emptied from the reservoir. Upon the same principles are the phenomena of intermitting springs explained.

§ 218. ***Barometer***. We know from experience, that the pressure of the atmosphere is not always the same; because it does not always support a column of quicksilver of the same height in the Torricellian tube. (§ 209.) Upon this is founded the theory of the barometer, which is an instrument for measuring the pressure and elasticity of air, at any time. It is made of a glass tube, nearly 3 feet long, and filled with mercury, like that of Torricelli; but the lower end is bent upwards again, and ends in a small open basin. (See the figure.) The column of quicksilver supported in the tube is commonly from 28 to 31 inches, leaving an entire vacuum in the upper end of the tube above the mercury. The upper 3 inches (from 28 to 31) have a scale attached to them, for measuring the length of the column at all times, by observing which division of the scale the top of the quicksilver is opposite to; as it ascends and descends within these limits, according to the state of the atmosphere.

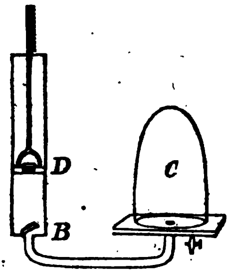
Fig. 129.



The weight of the column of quicksilver in the tube, which is equal to the pressure of the atmosphere, may at all times be computed, being nearly at the rate of $\frac{59}{120}$ of a pound avoirdupois weight, for every inch of quicksilver in the tube, on every square inch of base. Consequently, when the barometer stands at 30 inches, which is nearly the medium of the standard height, the whole pressure of the atmosphere is equal to 14¾ lbs. on every square inch of base; and in the same proportion for other heights. From this the pressure of the atmosphere on the surface of bodies and animals may easily be calculated. The reason why we do not feel this pressure is because it is equal on all sides, and counterbalanced by the fluids in our bodies, with which it is in equilibrium.

§ 219. To illustrate the different *mechanical* properties of air,—and indeed only these can come within the limits of this treatise,—we make use of the air-pump, an instrument invented by Otto von Quericke, in the 17th century.* It is similar in construction and operation to the water-pump, described in § 212, and consists principally of a brass barrel, bored and polished, truly cylindrical, to which is fitted a turned piston, furnished with a valve, opening upwards. The end of the barrel communicates, by means of a narrow tube, with the receiver, C. In B is another valve, opening upwards. By lifting up the piston, there is a vacuum between B and D, to fill which, the air from the receiver opens the valve B, and expands itself into the barrel, occupying more space than before, when it filled the receiver alone, and being consequently rarefied. The piston is now moved down, when the air in the barrel closes the valve B, and escapes through the other valve, D; another stroke of the piston exhausts another portion of the already rarefied air in the receiver. And so may the rarefaction of the air in the receiver be carried on to nearly $\frac{1}{300}$ of its original density.†

Fig. 130.



It is evident that the vacuum created, in this manner, in the receiver, C, is not so perfect as that in the Torricellian tube (§ 209); for, let the air in C be ever so much rarefied, a small portion of it will always remain. It is customary to place a small barometer under the receiver, to measure the diminished pressure, and consequently the degree of rarefaction of the air in C, by the falling of the quicksilver. The plate on which the receiver stands is provided with a turncock to let in the air from without, when the experiment is finished.

* He performed his first experiment at Regensburg, before Emperor Ferdinand III., in 1654.

† The further description of this instrument, and the contrivances made to facilitate its use, does not belong to a text-book. It is better explained verbally by the instructer, when exhibiting the apparatus.

§ 220. With a good air-pump the following remarkable experiments may be made :—

1. A closed bladder, only partly filled with air, expands itself in the rarefied air of the receiver.

2. A thin glass bottle, shut air-tight, and placed under the receiver, is burst by the elasticity of the air which is enclosed in it.

3. A bladder but little filled with air, and attached to a piece of lead, which makes it sink in water, expands itself, and rises again to the surface.

4. The air escapes from a vessel whose orifice is placed under water, and the liquid enters into it, when the air from without is let into the receiver.

5. Water ceases to run from a siphon.

6. The falling of a feather and of a piece of lead, or any other substance, is equally accelerated by gravity. (§ 74, page 63.)

7. Cork-wood and lead, which are in equilibrium in a balance, are no longer so in rarefied air.

8. A ball from which the air has been pumped, weighs less than one that is filled with it.

Thereby the specific gravity of air has been ascertained, which is about 0.008, taking that of distilled water = 1.

9. The sound of a bell, or of a chord, becomes weaker in rarefied air, and finally ceases entirely.

10. An animal suffocates in very rarefied air; a candle is extinguished; flint ceases to strike sparks from steel, &c.

11. Ether, and other subtile fluids, evaporate when the pressure of the atmosphere is removed.*

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* The teacher may now ask the pupils to explain some of these phenomena, from the principles learned in this and the preceding Chapter.

RECAPITULATION.

Mechanical Properties of the Atmosphere.

[§ 206.] By what is our earth every where surrounded?

What experiments and facts convince you of the existence of the atmosphere?

[§ 207.] What is the probable height of our atmosphere? What kind of fluid is the air which composes our atmosphere? Why is air an elastic fluid?

[§ 208.] Is air an *elastic* fluid? Why?

How can you prove this by an experiment? What experiments and facts can you adduce to prove your assertion?

[§ 209.] *Does air, like the liquids spoken of in the preceding chapter, obey the laws of gravity?* What remarkable experiment proves this? and how do you explain this experiment?

Was this property of air known to the ancients?

How, then, did they explain the phenomenon you have just described?

[§ 210.] What takes place if, in the last experiment, the tube is 3 or 4 feet long? *What important law do we derive from it?*

What is the space between the quicksilver and the closed end of the tube called?

[§ 211.] If, instead of quicksilver, the tube be filled with water, what is the height of the column supported in the tube by the pressure of the atmosphere?

(Here the teacher might require the pupil to repeat the hydrostatic law of § 184, page 163, and show its intimate connection with the law stated in this paragraph.)

[§ 212.] What remarkable phenomenon does this property of air explain? What are the principal parts of a sucking-pump? Explain their operation.

What other phenomena does the same property of atmospheric air explain?

[§ 213.] What law follows from the elasticity and gravity of the atmosphere?

How is this law proved? Why is the pressure of air in a room which communicates with the atmosphere, the same as that of the air without?

(The teacher may again refer to § 197, page 168, and require the repetition of it from the pupil.)

[§ 214.] How does heat affect atmospheric air? If a portion of air is shut up in a vessel, and then heated, is the pressure on the sides of the vessel diminished, or increased? What takes place, if, in this state, the vessel is provided with an aperture?

What takes place, if, after expelling, in this manner, a portion of air from a vessel, the vessel is suddenly cooled down again? What, if the aperture of the vessel is immersed in water?

[§ 215.] Does air, which is expanded by heat, remain in its place? What position, then, does it assume? Why?

What phenomena can you explain by this principle?

[§ 216.] By what means may all elastic fluids, consequently, also, atmospheric air, be compressed? How is this done?

What are the principal parts of a condensing machine? Explain their operations. *What remarkable relation is there between the density of the compressed air, and the degree of the compressing power?*

[§ 217.] What does a siphon consist of? If a siphon is filled with water, and then inverted, with the two open ends downwards, and held level in this position, what takes place, when the legs are equal? What, when these are unequal, or when the siphon is inclined?

Explain each of these cases. How does the operation of the siphon affect the surface of a liquid in a vessel, when the shorter leg of a siphon is immersed in it, and the liquid is set a running from the other (longer) leg? How must the siphon be situated, if the whole basin shall be drained by it? What remarkable phenomena does the theory of the siphon explain? (Explain Fig. 128.)

[§ 218.] Is the pressure of the atmosphere always the same at the same place? What experiments convince us

that it is not so? What kind of instrument is a barometer? What is it made of? How is it constructed?

How can you compute the weight of the column of quicksilver in the tube, which is equal to the pressure of the atmosphere? What is the reason we do not feel the pressure of the atmosphere?

[§ 219.] By what instrument can the different *mechanical* properties of air be illustrated? What are the principal parts of an air-pump? Explain their operation. How far can the rarefaction of air in the receiver be carried?

Is the vacuum created in the receiver of an air-pump as perfect as that in the Torricellian tube? Why not?

[§ 220.] What are the principal experiments which can be made with an air-pump?

How can you explain them?

CHAPTER VII.

OF HEAT.

§ 221. In the vicinity of certain bodies, or in contact with them, we feel either *heat* or *cold*, and designate by these words sensations which do not admit of any further description.

It is customary, also, to call the bodies which produce these sensations, *cold* or *warm*; but it is certain, that we cannot tell what body is absolutely cold or warm, and that our sensations tell us only what body *feels* so in comparison with another.

§ 222. The principle by which all bodies are more or less capable of producing the infinite degrees of sensation of heat, or, in other words, the primitive cause of all phenomena of heat and cold, is as yet perfectly unknown. Most modern philosophers, however, are of opinion that they proceed from a certain imponderable, exceedingly subtile substance, termed *caloric*, which penetrates all bodies, and, on account of its elasticity, endeavors incessantly to be every where in perfect equilibrium.*

* Professor Meissner, of the Polytechnic School of Vienna, has endeavored to show, by a series of brilliant experiments, that caloric is actually a ponderable substance. (See his Elements of Chemistry; Vienna, 1816.) But the expansion of all bodies by heat, and the consequent diminution of their absolute weight, by displacing a greater bulk of air, may not, perhaps, have been sufficiently taken notice of. Most French chemists, the most celebrated philosophers in Germany, and, above all, the greatest chemist now living, Berzelius, in Sweden, are for the existence of caloric. The greatest opponents to this system are Count Rumford and Sir Humphrey Davy. William Henry, of Manchester, has shown that the arguments of the latter against a self-existing, heat-producing principle, are fallacious, or, at least, as far as they go, insufficient.—For further information, see Gilbert's Annals of Natural Philosophy, Vol. XII. page 546: Gehler's Physical Dictionary; article Heat: A. Lorenz' Chemical and Physical Investigation of Fire; Copenhagen, 1789. Also, Tobias Mayer's Natural Philosophy: Gilbert's Annalen der Physick: Gehler's Physicalisches Wörterbuch: A. Lorenz, Chemisch-Physicalische Untersuchungen über das Feuer; Copenhagen and Leipzig, 1789.

MEANS OF PRODUCING HEAT.

§ 223. There are four principal means of producing heat:—

1. By friction.

Hence the heat produced by the boring, filing, or hammering of metals; by wire-drawing, by turning, &c. These phenomena take place, also, under the receiver of an air-pump.

2. By chemical operations; such as solutions, fermentations, putrefactions, &c.

Instances of this kind are, all solutions of metals in acids, iron and water, limestone and water, &c. Dung, flour, malt, and wet hay, cause, under certain circumstances, spontaneous combustion. Finally, the heat produced in the animal and human body, by the process of respiration and digestion.

3. By exposing a body to the light of the sun, which is the principal source of all heat upon our earth.

Hence the immense heat produced by the reflection of sunbeams from a concave mirror.

4. By bringing colder bodies in contact with heated ones. In this case, the heat of the one will communicate itself to the other, until it is in both in perfect equilibrium.

§ 224. *Heat expands all Bodies.* All bodies are expanded by heat, and assume again their former bulk, when exposed to cold.

This may be shown by numerous experiments. A heated iron ball passes no longer through a hole, through which it went when cold; a bladder only partly filled with air, is expanded over a coal fire; a hollow glass ball, which floats upon cold water, sinks to the bottom when the water is heated; &c. Wood *shrinks* when exposed to heat, through the evaporation of the fluids contained in its pores. The same takes place with clay in the manufacturing of bricks, &c.

§ 225. *Unequal Expansion of Heat.* Heat does not expand all bodies in the same degree; air is expanded quicker than liquids, and liquids quicker than solid bodies.

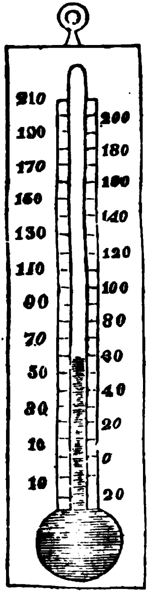
§ 226. The expansion of liquids or solid bodies is found, by experiment, not to be proportional to the degree of heat; that is, equal degrees of heat do not occasion in them equal degrees of expansion. Elastic fluids differ in this respect

from liquids and solids, their expansion being proportional to the successive degrees of heat applied to them.

The cohesive attraction in solids and liquids being greater than in air, the first portions of heat applied to them, find more resistance than the following ones. Moreover, we have to consider, that both liquids and solid bodies, when under the influence of certain degrees of heat, begin to change their aggregate forms. (§ 30, p. 28.) Thus, when water is very nearly heated to a certain degree, it becomes transformed into steam, and is therefore expanded much quicker than at inferior degrees. When once transformed into steam, its expansions are, like those of other elastic fluids, proportional to the degree of heat applied to it.

§ 227. *Thermometer*. The expansion of bodies by heat, and their contraction by cold, afford the means of measuring degrees of temperature. The instrument used for this purpose is called a *thermometer*.

Fig. 131.



It is made of a hollow glass tube, which, having a hollow ball at the bottom, is nearly half filled with quicksilver.* When this is done, the whole is heated until the quicksilver rises quite to the top. The top is then hermetically sealed; that is, so as perfectly to exclude all communication with the outward air. Then, in cooling, the quicksilver contracts, and, consequently, its surface descends in the tube, until it comes to a point which corresponds to the temperature of the air. When the atmosphere becomes warmer, the quicksilver expands, and rises in the tube, and contracts and descends again when the atmosphere becomes cooler. By the side of the tube is placed a scale, which is prepared thus:—The thermometer is brought into the temperature of freezing, by immersing the ball in water just freezing, or in ice just thawing, and the scale is marked where the quicksilver then stands, for the point of

* This fluid is now generally used for thermometers, it being very susceptible to the different degrees of heat; enduring great heat before it becomes transformed into vapor, and great cold before it becomes solid.

freezing. Then it is immersed in boiling water, and the scale again marked, where the surface of the quicksilver then stands. The distance between these two points is divided into 180 equal divisions, or degrees, and the same degrees are continued to 32 degrees farther below, which point is then called zero; and as much below zero, and above the boiling point, as is convenient; so that there are 212 degrees from the boiling point down to zero.

Fahrenheit found that the quicksilver always descended to 0 (namely, to the point which he called *zero*), by placing the ball in a mixture of equal parts of snow and salammoniac. From him the above division of the scale is called *Fahrenheit's*. Fifty-five degrees of this division mark the mean temperature of this country; and it is in this temperature, and in an atmosphere which sustains a column of 30 inches of quicksilver in the barometer, that the specific gravities of bodies are ascertained.*

Besides the scale just described, there are others, which are particularly used on the continent of Europe. Among those are Réaumur's, dividing the space from the freezing point (which he calls *zero*) to the boiling point into 80 degrees; and De L'Isle's, on which the degrees are counted downwards, dividing the space from the boiling to the freezing point into 150 equal parts; and Celsius's, or the centesimal scale, in which the distance between the boiling point and the freezing point is divided into 100 equal parts. It is exceedingly easy to deduce the degrees of one division from those of the other. Thus, 2¼ degrees Fahrenheit making one degree of Réaumur's scale, we can change Fahrenheit's degrees into Réaumur's by subtracting 32 from their number, and dividing the remainder by 2¼. There are also thermometers in which air is the fluid through whose expansion the degrees of heat are ascertained; but they require so many corrections and precautions in practice, that they are almost entirely out of use.

To indicate great degrees of heat, Wedgewood made use of pure clay, which contracts to about one fourth of its bulk, from the time it acquires a red heat until vitrification. It is to be regretted, that the clay-cylinders, or parallelopipeds, which are used for this purpose, change, in course of time, which makes them incapable of indicating great degrees of heat. On this account, Wedgewood himself does no longer manufacture them.†

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* See Hutton's Mathematics, edited by Robert Adrian. Vol. II. page 234.

† A full description of this instrument, and the degrees of heat indicated by it, compared with Fahrenheit's scale, may be found in the Library of Useful Knowledge; article Heat, page 19.

DIFFERENT CAPACITIES FOR HEAT.

§ 228. We know from experience, that the same quantity of heat, imparted to two different substances, produces in them unequal degrees of temperature, when measured with the thermometer. This we ascribe to the greater or less capacity which these substances have for absorbing heat, and *call the capacity for heat greater in that body which requires a greater quantity of heat than another to produce the same degree of temperature.* Thus the capacity of water is greater than that of quicksilver, because, when exposed, during the same time, to the same degree of heat, quicksilver exhibits a greater degree of temperature, by the thermometer, than water; which shows that water *absorbs* more heat.

§ 229. *Manner of ascertaining the Capacity for Heat.* There are various ways to ascertain the capacities of bodies for heat. One is, to bring equal portions of different substances in contact with each other. It is then found that the mixture never exhibits the mean temperature between them. A pound of water, for instance, heated to 156 degrees, and mixed with a pound of quicksilver, at 40 degrees, produces a common temperature of 152, instead of 98, the exact mean.

In this experiment, the water lost 4 degrees, and the quicksilver gained 112; which proves that the quantity of heat which is required to raise one pound of quicksilver from 40 to 152 degrees, is equal to that which is required to raise one pound of water from 152 to 156. Thus the capacity of water for heat is to that of quicksilver as 112 to 4, or, which is the same, as 28 to 1.

§ 230. In a similar manner to that we have just described, have some philosophers (particularly Crawford, Wilcke, Kirwan, and Gadolin) determined the capacities for heat of many different substances, and compared them with that of water. These comparative capacities for heat they then called *specific capacities*, or *specific caloric*. (See Table II. at the end of the book.)

§ 231. *Different Quantities of Caloric in Bodies of equal Temperatures.* From what we have said, it is easily perceived, that, if there be such a self-existing substance as caloric, it does not exist in equal quantities and densities in

all bodies, although they may show the same degree of temperature by the thermometer.

§ 232. Every change in the relative position of the particles and interstices of bodies, changes also their capacities for heat. This is particularly the case when solid bodies become changed into liquids, or liquids into elastic fluids. They then absorb great quantities of heat, without showing any increase of temperature by the thermometer. Heat is then said to be *engaged* or *latent* in these bodies. And it also frequently happens, that bodies become changed from the fluid state into the liquid, or from the latter into the solid state; in which cases their temperature is increased, without any new addition of heat. Heat is then said to become *disengaged* or *free*.

Hence the cold felt when air or vapors expand themselves rapidly (because in this state they absorb caloric); the quantity of heat which must enter into metals before they melt; the quantity of heat requisite to change water into steam, &c.

§ 233. When two or more substances are mixed together, their chemical affinities frequently change the mean sum of their capacity for heat. In this case, the mixture absorbs more heat (caloric), and causes the sensation of cold. These phenomena are more fully treated of in Chemistry.

This takes place, for instance, when salts are dissolved in water; when snow is mixed with muriate of soda, or water with diluted spirit of wine, or nitrate of ammonia; when snow is melted in water, or mixed with muriate of lime, &c.

§ 234. *Influence of Light on Heat.* It is not improbable, that light, by striking upon bodies, changes their capacity for heat, and thereby disengages caloric. This seems to be corroborated by the circumstance, that those bodies through which light *passes* easiest, or which *reflect* light most, are least heated by it; whereas, dark and opaque bodies become sooner warm.

White bodies, glass, water, &c., are not easily heated by sunlight. A thermometer held in the sun rises higher when the ball is made black. Strips of cloth of different colors, placed upon snow, sink the deeper the darker the color is.* Dark cloths are warmer than white ones, &c.

* These experiments were first made by Dr. Franklin, and are described in his Letters on Philosophical Subjects.

PROPAGATION OF HEAT.

§ 235. *Velocity of Heat.—Heat does not pass through all bodies with the same degree of velocity.* When thin cylinders of silver, glass, or wood, are held with one end in the flame of a candle, the silver will soon be too hot to hold; while the glass will be much longer in being heated, and the wood will burn at one end before the least sensation of heat is felt at the other. Those substances which become hot soonest at the farthest end from the flame, are said to be the best *conductors of heat.*

§ 236. The densest bodies, consequently metals, are the best conductors of heat. Earthy substances are in this respect inferior to metals; wood is still more so; and atmospheric air, when not in motion, is accounted to be the worst conductor of heat. Among solid substances, the coverings (skins) of animals have the least conducting power.

The worst conductors among these are hare's fur and eider down; and this property is probably owing to the bulk of air which is contained among their particles. For the same reason are the warmest articles of clothing those which have the longest nap, fur, or down; and the imperfect conducting power of snow arises probably from the same cause. It is stated, that, in Siberia, while the temperature of the air has been 70 degrees below the freezing point (38 degrees below zero of Fahrenheit's scale), the surface of the earth, protected by a covering of snow, has rarely been 32 degrees (zero of Fahrenheit's scale).*

§ 237. *Use of Imperfect Conductors of Heat.* The imperfect power of conducting heat, in some substances, is taken advantage of for the purpose of confining heat. Furnaces are surrounded by coats of clay, trees by straw; double windows are used in winter, throughout Germany and the north of Europe, in order to prevent the escape of heat from the rooms, by a column of air enclosed between the windows, &c.

§ 238. The same substances which *prevent* the escape of heat, are equally effectual in preventing its admission.

* See Library of Useful Knowledge; article Heat, page 23.

Hence the air under a thatched roof, although warmer in winter, is cooler in summer, than the air under a roof of tile or slate. Straw, which keeps a fig-tree from freezing in the winter, keeps the heat from an ice-house in summer, &c.

§ 239. *Different Sensations of Heat produced by different Bodies of the same Temperature.* The different sensations we have on touching different substances, although of the same temperature by the thermometer, must be ascribed to their different powers of conducting heat. The best conductors must feel coldest to the touch, because they absorb the heat from the hand quicker than imperfect conductors of heat. It is for this reason that iron feels colder than glass, and the latter colder than wood, although they be all in the same room, and of the same degree of temperature.

§ 240. *Free or Sensible Caloric.* It is yet to be observed, that solid substances conduct heat in all directions —upwards, downwards, and sideways—with nearly the same facility. On this account, the heat which they conduct is called *free* or *sensible* caloric.

§ 241. But it has been found by experiments, that heated bodies, when exposed to the air, lose part of their heat, also, by *radiation;* that is, by part of their heat flying off, in right lines, from every point in their surface.

The principal experiment on this subject is made with two concave reflectors of tin plate, placed at a distance of several feet, exactly opposite each other. Then, by placing a heated iron ball, which shall not be red, in the focus of the one, and the ball of a mercurial thermometer in the focus of the other, the mercury in the thermometer will instantly rise, even if a transparent glass plate be placed between it and either of the reflectors. Any other hot substance, used instead of iron, produces the same effect.

§ 242. Some natural philosophers are of opinion, that radiant heat moves with a velocity equal to that of light; but this seems to be more than doubtful. All we know about it from experiments is, that radiant heat moves with such a velocity as to require no perceptible interval of time to traverse the space of 69 feet.*

Whether the phenomena of radiant heat are really produced

* See Pictet's Experiments on Fire.

by projections of calorie, emanating from every point in the surface of a heated body, or whether they are occasioned by expansions and contractions of heated particles of atmosphere, like the rays of sound (§ 137, page 113), is not yet decided among philosophers. Professor Leslie, of Edinburgh, is of the latter opinion, and has made a series of brilliant and interesting experiments, eminently calculated to corroborate his hypothesis.

§ 243. *Fusion of Solids.* When solid bodies are for some time exposed to great degrees of heat, their cohesive powers are overcome; they lose their texture, and consequently become liquid. This is called the *melting* or *fusion* of solids. When still greater degrees of heat are applied, then solid and liquid substances become transformed into steam, or vapors, which process is called the *evaporation* of bodies.

§ 244. *Evaporation.* The degree of heat, at which solid bodies melt, or liquids evaporate, varies in different substances, and seems to depend, in some measure, on the cohesive power of their particles. Some substances appear to us liquid or as elastic fluids, at the lowest stages of temperature; and there are others which require great degrees of heat to be exhibited in this form. Most solid bodies have been converted into liquids, and the greater part of these into vapors, by the intense heat produced by galvanic electricity.

§ 245. *Boiling of Liquids.* Liquids may become transformed into steam so quickly as to be thrown into an undulating motion, which is called the *ebullition* or *boiling* of liquids. The portion of air which is generally contained in them, is, by this process, expelled; wherefore the boiling of liquids is a means of purifying them.

§ 246. Some bodies boil at very low degrees of heat (for instance, ether and spirits of wine), particularly *when the pressure of the atmosphere is removed.* (See Table III. at the end of the book.) In general, we may lay down this principle, *that the pressure of the atmosphere, and pressure in general, is an obstacle to the boiling of liquids.*

This is the reason why liquids boil sooner upon the top of high mountains, and under the receiver of an air-pump, than under the pressure of the whole atmosphere. Without this pressure of the atmosphere, it is probable that many fluids would not be known otherwise than in the elastic state.

§ 247. When a liquid boils, it ceases to assume a higher degree of heat. All the heat which is further added, is employed in the formation of steam. But when the vessel is closed, in such a manner that the steam is prevented from passing off, then the liquid can assume a degree of heat far surpassing the boiling point. Steam, which is thus shut up in a vessel, is capable of exercising an immense pressure, and is now universally employed in machinery.

Here the teacher might give a description of the steam-engine, and its application. (An excellent and cheap model of it has lately been prepared by Mr. Claxton, a skilful mechanic of Boston.)

§ 248. *Decomposition of Steam.* When the degree of temperature is reduced by mechanical pressure, steam loses its elasticity, and returns to its liquid state. This process is called the *condensation of steam.*

§ 249. *Absorption of Heat by Steam.* No formation of steam or vapor can take place without absorption of heat. (§ 244, page 194.) Hence the surrounding bodies must lose a portion of their heat, and become cooler. This serves to explain a number of phenomena; the cooling of rooms in summer, by sprinkling them with water; the sensation of cold, experienced by wetting the hand with spirits of wine or ether, and suffering these substances to evaporate upon it; the refreshing coolness felt in summer after a bath, &c.

§ 250. *Fog—Mist.* When steam, either by a diminution of heat, or by pressure, begins to be condensed, it forms a great number of exceedingly little drops, whose specific gravity is not sufficiently great to overcome the resistance of air, and which remain, therefore, suspended in the atmosphere. In this state they are visible, and form what is commonly called a *fog*, or *mist.* Such a mist or fog is always formed, when the steam from a boiling liquid escapes into a cooler atmosphere.

§ 251. *Evaporation—Exhalation.* Atmospheric air changes continually, and at all degrees of temperature, a certain portion of water into steam. This process, which is carried on much slower than the formation of steam by intense heat, receives the name of *evaporation*, or *exhalation.* Our atmosphere is, in this manner, constantly filled with an immense quantity of steam and vapor, which, as long as it is perfectly elastic, is dry and pellucid; but when

it separates again from the atmosphere, by being cooled down, or condensed, it appears as fog, mist, or clouds, and finally descends as rain or snow.

§ 252. *Rain and Snow.* Steam and vapors which are not perfectly dissolved in the atmosphere, frequently adhere to other substances, and thereby damp and wet them. In this state, they are often sucked in by the adhesive attraction of these bodies, which, by the degree of their subsequent expansion, indicate the dampness of the atmosphere.

Upon this principle is founded the theory of the hygrometer, which is an instrument for measuring the dampness of the atmosphere. The hygrometrical substance is either a human hair (Saussure's), or cat-gut (Lambert's), or whale-bone (De Luc's). They are all too imperfect and variable to give any results to be relied upon, and deserve, therefore, as yet, no place in a text-book.

§ 253. *Congelation—Freezing.* When liquids are exposed to certain degrees of cold (which is either done by bringing them in contact with colder bodies, or by exposing them to the influence of a colder atmosphere), they congeal and become solid. This is called the *congelation* or *freezing* of liquids. All liquids, with the exception of alcohol, have been reduced to the solid state; but very different degrees of cold are required for this purpose, in different substances. (See Table IV., at the end of the book.)

§ 254. When the process of congelation is going on slowly, so that the particles of the liquids have time to follow their mutual cohesive attraction, they assume regular geometrical forms, and the solids thence obtained are termed crystals. (See § 50, page 43.)

§ 255. When water is changed into ice, it receives a regular texture, and becomes porous. On this account, its volume is greater than that of the water from which it is obtained, the ratio being nearly as 9 to 8.

This explains why glass and other vessels burst when water freezes in them; why trees and rocks burst in severe winters, &c. But so long as water remains liquid, it contracts by cold, and reaches its greatest density a few degrees above the freezing point.

§ 256. It remains to be observed, that heat is a powerful *chemical agent.* All chemical combinations, namely,

take place sooner, when the bodies are brought to a certain degree of temperature; and there is hardly any chemical process which is not more or less accompanied with an absorption or disengagement of heat. These phenomena, however, form no part of Natural Philosophy, and are more properly treated of in Chemistry.

RECAPITULATION.

Of Heat.

[§ 221.] What do the words *heat* and *cold* designate?

What do you call bodies which produce in us the sensation of heat or cold? Is it possible for us to tell what body is absolutely cold or warm? What, then, do our sensations of cold and warm tell us?

[§ 222.] Do we know the principle or cause by which all bodies are more or less capable of producing degrees of heat? What is the opinion of modern philosophers on this subject?

Means of Producing Heat.

[§ 223.] What are the four principal means of producing heat?

Give instances of heat produced by friction; of heat produced by chemical operations; and of great heat produced by the light of the sun.

[§ 224.] In what manner does heat affect the volume of bodies?

What experiments can you mention to prove this universal law?

[§ 225.] Does heat expand all bodies in the same degree? Which is expanded quickest, air, liquids, or solid substances?

[§ 226.] Is the expansion of liquids and solids proportional to the degrees of heat? or, in other words, do equal

degrees of heat produce equal degrees of expansion, in liquid and solid substances? How do elastic fluids differ, in this respect, from liquids and solids?

How can you account for these unequal degrees of expansion by heat? What influence has the aggregate form of liquids and solids on their expansion by heat? Do the degrees of expansion remain unequal, after the body is transformed into vapor?

[§ 227.] What means have we to measure degrees of temperature? What is the instrument used for this purpose called? How is a thermometer constructed?

How many degrees of Fahrenheit's scale mark the mean temperature of this country? Is Fahrenheit's scale the only one now in use? What other scales are there? How many degrees of Fahrenheit are equal to 1 degree of Réaumur? Is quicksilver the only fluid used for the construction of thermometers? What means did Wedgewood employ to measure great degrees of heat?

Different Capacities for Heat.

[§ 228.] Does the same quantity of heat, imparted to two different substances, produce in them the same degree of heat, when measured with the thermometer? To what do we ascribe this difference? *When do you call the capacity of a body for heat greater than that of another body?* Give instances of different capacities for heat.

[§ 229.] What means have we to ascertain the different capacities of bodies for heat? Give an example.

What ratio does the capacity of water for heat bear to that of quicksilver?

[§ 230.] To what did Wilcke, Crawford, Kirwan, Gadolin, and others, compare the capacities of different substances for heat? What did they call these capacities?

(Here the teacher may explain or require the explanation of Table II.)

[§ 231.] If there be such a self-existing principle as caloric, does it exist in equal quantities and densities in all bodies?

[§ 232.] What does every change in the relative position of the particles and interstices of a body necessarily

produce? When is this particularly the case? When a body absorbs great quantities of heat without showing any difference of temperature on a thermometer, what is the heat which enters the body said to be? What is heat said to be, when a body indicates a higher degree of temperature, without receiving any additional quantity of heat?

What phenomena does this principle explain?

[§ 233.] When two or more substances are mixed together, is the resulting capacity of the mixture always equal to the mean sum of their capacities?*

Give instances where this does actually take place.

[§ 234.] Is it probable that light, by striking upon bodies, changes their capacity for heat? What circumstances seem to corroborate this supposition?

Give instances of this kind.

Propagation of Heat.

[§ 235.] *Does heat pass through all bodies with the same degree of velocity?* Can you tell me of an experiment which proves that heat does not pass through all bodies with the same velocity? What are those substances called, which soonest become hot when exposed to heat?

[§ 236.] What bodies are the best conductors of heat? What bodies (among solids) have the least conducting power?

Which are the worst conductors among the coverings of animals? What is this property probably owing to? Why is snow a bad conductor of heat? What remarkable phenomenon does this explain?

[§ 237.] How is the imperfect conducting power of some substances taken advantage of? Why are furnaces surrounded by clay, trees by straw, &c.? What is the use of double windows in winter?

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* By the *mean sum* is meant the *arithmetic medium* of their capacities. Thus, if the capacity for heat is in one body 3, and in another 5, the mean sum of their capacities would be $\frac{5+3}{2}=4$. Now, if the resulting capacity is more than 4, the mixture will absorb heat, consequently produce cold.

[§ 238.] What bodies prevent most effectually the admission of heat? What is the reason that the air, which, under a thatched roof, is warmer in winter, is yet cooler in summer, than the air under a roof of tile or slate? Why does straw keep the heat from an ice-house in summer, when the same substance prevents a fig-tree from freezing in winter?

(The answer to the two last questions is the same, viz. 'Because the same substances which prevent the escape of heat, are equally effectual in preventing its admission.')

[§ 239.] How can you account for the different sensations of heat which we have, when touching different substances? How must the best conductors feel to the touch? Why? Why does iron feel colder than glass, and the latter colder than wood, although all be in the same room, and of the same degree of temperature?

[§ 240.] In what direction do solid substances conduct heat? What is this heat (conducted by solids) called?

[§ 241.] In what manner does a heated body lose its heat, when exposed to the air? What do you understand by radiation of heat?

What remarkable experiment can be made on this subject?

[§ 242.] Some natural philosophers are of opinion that radiant heat moves with a velocity equal to that of light: is this at all probable? What do we know about it with certainty?

Is there no other way to account for the phenomena of radiant heat, than by supposing them to be produced by actual *projections of caloric*? What is Professor Leslie's opinion on this subject?

[§ 243.] What changes do solid bodies sometimes undergo, when exposed to great degrees of heat? What do you understand by the *melting* or *fusing* of solids? What takes place when still greater degrees of heat are applied to these bodies? In what consists the process of *evaporation?*

[§ 244.] Is the degree of heat at which solid bodies melt, the same in all substances? On what does it seem to depend? What effect does heat produce on most solid bodies and liquids we know of?

[§ 245.] What do you call that process by which a li-

quid is so quickly transformed into steam, as to be thrown into an undulating motion? Why is the boiling of liquids a means of purifying them?

[§ 246.] Does the pressure of the atmosphere facilitate, or is it a hindrance to the boiling of liquids? *What general law is there with regard to this pressure?*

What phenomena can you explain from this principle? What would be the state of many liquids, without the pressure of the atmosphere?

[§ 247.] Can a boiling liquid be made to assume higher degrees of heat? What becomes of the heat which is further added? Does the same rule apply when the vessel is closed in such a manner that the steam is prevented from passing off? What is the steam which is thus shut up capable of exercising?

[§ 248.] What becomes of steam when its temperature is reduced, or when some mechanical pressure is applied to it? What do you call this process?

[§ 249.] Can the formation of vapor or steam take place without absorption of heat? How, then, does this process affect the surrounding bodies? What phenomena does this explain?

[§ 250.] What does steam, which, by a reduction of temperature, or by mechanical pressure, begins to be decomposed, form in the surrounding atmosphere? What name do these visible drops which remain thus suspended in the atmosphere, receive? When is such a fog or mist formed?

[§ 251.] What effect does atmospheric air continually produce on a certain portion of water? What do you call this process? What is the difference between it and the formation of steam? * Do we feel or perceive the immense quantity of steam and vapor with which our atmosphere is continually charged, as long as both are perfectly elastic? What becomes of them when they are cooled down, or condensed?

[§ 252.] In what manner do steam and vapor, which

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* It is carried on much slower than the formation of steam.

are not perfectly dissolved in the atmosphere, affect other substances? When, in this state, they are sucked in, or absorbed, what do these substances, by the degree of their expansion, indicate?

What instrument is constructed upon this principle? What is the hygrometrical substance in Saussure's hygrometer? What is it in Lambert's? What, in De Luc's?

[§ 253.] How are liquids affected when exposed to certain degrees of cold? What is this process called? What liquids have by this means been reduced to the solid state? Is the same degree of cold required for the congelation of all liquids?

(Here the teacher ought to explain, or require the explanation of Table IV., at the end of the book.)

[§ 254.] What takes place, if the process of congelation is going on slowly, so that the particles of the liquids have time to follow their mutual cohesive attraction? What are the solids, which are obtained in this manner, called?

[§ 255.] When water is changed into ice, what does it always receive? Does its volume become greater or smaller by freezing? In what ratio does it increase?

What phenomena does this explain? How is water affected by cold, as long as it remains liquid? When does it reach its greatest density?

[§ 256.] What effect does heat produce on chemical combinations? What is every chemical combination more or less accompanied with?

CHAPTER VIII.

OF LIGHT.

§ 257. *Nature of Light.* Light is one of the most powerful agents in the whole material world. Its nature has not yet been ascertained. Two very opposite opinions, however, have been maintained by philosophers, with regard to its origin and its propagation. Some suppose it to consist of *material particles, emanating from the luminous body, with immense velocity, and in all directions* (Sir Isaac Newton's hypothesis); while there are others (Huygens, Euler, Young, &c.) who believe it to be *a fluid diffused through all nature, and in which vibrations and undulations are produced by the action of the luminous body*, which are then propagated through the air, in a manner similar to sound.

We shall adhere neither to the one nor the other hypothesis, but treat only of the laws of light, which are perfectly demonstrable by mathematical science.

§ 258. *Seeing.* The operation of light, or of luminous bodies upon the eye, is accompanied by a sensation which is called the *seeing* of bodies; and through it we become conscious of the situation, figure, magnitude, and motion of the luminous body.

§ 259. *Luminous and Illumined Bodies.* With respect to light, all bodies are either of themselves *luminous*, or they are *illumined* (receive light from others), so that we can see them.

Among the luminous bodies we count the sun, the fixed stars, phosphorus, some fishes, and insects, the flame of candles, lamps, &c. Light may also be produced by pressure, friction, putrefaction, and other chemical processes. Sometimes a luminous body is not seen when near another of a more intense light.

§ 260. *Reflected Light.* When the light which dark bodies receive from luminous bodies, is reflected by them

into our eyes, then they become visible, and we say that we see them. The light thus received is termed *reflected light*.

§ 261. *Transparency—Opacity*. Some bodies, instead of reflecting light, suffer a great quantity of it to pass through them. These are called *transparent*, or *pellucid;* while those which do not possess this property are termed *opaque* bodies.

Most liquids and crystals are transparent. Polished metals, being the best reflectors, suffer no light to pass through them, except when hammered out into very thin plates.

§ 262. *Light-magnets*. A third kind of bodies, which of themselves possess no light, have the faculty of becoming luminous, when exposed to sunshine, or to the intense light of a flame or candle, and continue afterwards to throw out light in the dark, for a considerable length of time. These are by some called *light-magnets*, or *absorbers of light*.

Instances of this kind are the diamond, phosphor of Canton, &c. Snow and ice probably belong to the same class of bodies.

§ 263. *Black and White Bodies*. All the light which falls upon dark bodies is not reflected by them. A portion of it is absorbed, or at least not reflected into our eyes. Those which absorb light most are called *black;* those which reflect it most are termed *white bodies*.

§ 264. *Propagation of Light.—Light is propagated in straight lines, with a prodigious velocity of about* 195,000 *miles in a second.*

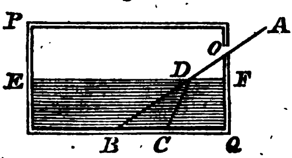
The first of these assertions (that light moves in straight lines) is proved by the fact that bodies cannot be seen through bent tubes, and it may also be inferred from the shadow which dark bodies cast. For the discovery of the velocity of light, we are indebted to Römer and Bradley, who have proved, from observing the eclipses of Jupiter's satellites, that light needs but 7 minutes to travel from the sun to the earth. From this immense velocity of light, it is plain that the velocity with which it traverses the greatest possible terrestrial distance, can neither be measured nor observed with the nicest time-keepers; as it would need but one twenty-fourth part of a second to travel from one point of the earth to the other.

§ 265. *Density of Light*. If light is propagated in rays or straight lines, its density decreases in proportion to the squares of the distances from the luminous body.

This law is established on the same principle on which we established a similar law for the propagation of sound (§ 137, page 113), and applies equally well to all propagation of motion or matter in form of rays.

§ 266. *Refraction of Light.* When a beam of light passes through a transparent body, it is first bent or broken from its direction, on its passage through that body, and then bent again on emerging from it. This is called the *refraction* of light; and its degree varies in different substances.

Fig. 132.



This may be illustrated by an experiment. Let PQ (Fig. 132) be a vessel, in one of whose sides is a small hole, O. Place a lighted candle at a distance of two or three feet from it, so that its flame is in A. A ray of light, proceeding from it, will pass through the hole, O, in a straight line, AB, and strike the bottom of the vessel at B, where it will form a small circle of light. But when the vessel is filled with water, up to EF, this circle of light, instead of being in B, will fall upon C, the beam of light being bent in the point D, where it strikes the water. These phenomena we shall notice more particularly hereafter.

§ 267. *Inflection of Light.* We know, also, from experience, that light is changed from its direction, when passing near the surface, edges, or corners of bodies, in which case it is said to be *inflected.*

This phenomenon, in the opinion of some philosophers, speaks for the materiality of light; inasmuch as they seek the cause of it in the chemical affinity which the substance of light has for these bodies, by the attraction of which it seems to be bent from its original direction.

§ 268. *Shade.* When light falls upon an opaque body, the latter casts a shade behind it, whose magnitude, shape, and position depend upon the magnitude and shape of the opaque body, upon its distance from the luminous body, and the direction of the light which strikes upon it. Its further theory belongs to Mathematics and the fine arts.

Let us now consider separately the three principal phenomena in the propagation of light—*reflection*, *refraction*, and *the formation of colors.*

1. REFLECTION OF LIGHT.

§ 269. *When a ray of light falls upon a polished surface, either plane or curved, it follows the laws of elastic bodies* (§ 114, page 105), *and is consequently reflected in such a way, that the angle of incidence is equal to the angle of reflection.*

This may be shown by an experiment (reflecting the light of the sun, or of a candle, from a looking-glass).

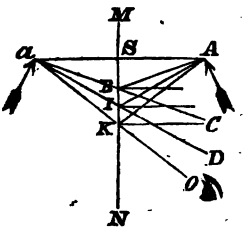
§ 270. *Mirrors.* Bodies which are commonly used to reflect light are called *mirrors.* They are made either of metal or glass, having their surface highly polished. Mirrors are either *plane, concave,* or *convex,* according as their surfaces are *plane* or *spherical* (the curvature turned *inward* or *outward*).

Glass mirrors must be quicksilvered on one side, in order to reflect more light. Metallic mirrors are the best reflectors; those of platinum admit of the highest polish.

A.—*Reflection of Light from Plane Mirrors.*

§ 271. *Law.—A luminous point before the mirror appears to the eye as if proceeding from a point situated exactly as far behind the mirror as the luminous point is before it.*

Fig. 133.



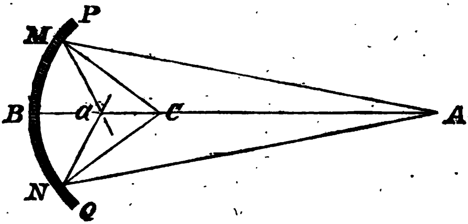
Let A (see the figure) be a luminous point; AB a ray of light striking the plane mirror, MN; BC the same beam AB, reflected from the mirror, MN; then, by extending the reflected ray BC in the direction B*a*, it will cut the perpendicular A*a* in such a manner, that the distance *a*S is equal to AS. In the same manner will every other ray, emanating from the same luminous point, A, be reflected as if coming from the point *a* behind the mirror: an eye in O, therefore, will receive *the reflected rays,* AB, AS, AR, &c., *as if proceeding from the point a, which is exactly as far behind the mirror as the luminous point,* A, *is before it.*

§ 272. The point a, behind the mirror, from which the rays of light seem to proceed, is called the *image* of the luminous point, A, before it. The law just found for a luminous point applies equally to a whole object, *which will, therefore, appear behind the mirror, at the same distance, and have the same situation and magnitude which it has before the mirror.*

B.—*Reflection of Light from Spherical Mirrors.*

§ 273. *Law.—The image, a, of a luminous point,* A, *before a spherical concave mirror,* PQ, *lies always in a straight line,* AB, *drawn from the luminous point through the centre,* C, *of the circle,* PQ, *of which the mirror makes a part.* This straight line is called the *axis* of the mirror.

Fig. 134.



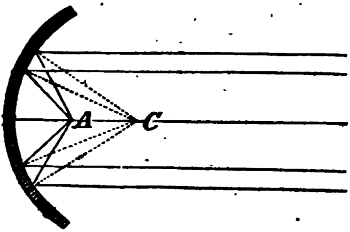
Let C be the centre of the spherical mirror, PQ; CM its radius; A, the luminous point before the mirror; AB, a straight line from A, through the centre, C; AM, a ray emanating from A. Then, the angle of incidence, AMC, being equal to the angle of reflection, CMa, it follows that Ma is the reflected ray; and in a similar manner it may be shown, that every other ray proceeding from the luminous point, A, is likewise reflected to the point a; wherefore, a will be the image of A. And if the point A is situated differently with regard to the concave mirror, PQ, it will still be found, that its image lies in a straight line, drawn from the point A, through the centre of the mirror.* If a were the luminous point, then aM would be an emanating ray, MA the reflected ray, and the point A the image of a. This is sufficiently plain from inspection. (See the figure.)

* When the mirror is an arc of more than 10 degrees, there will be some incorrectness in the reflection of rays, and the image in a will not be distinct.

§ 274. *Focus, or Burning Point.—When parallel rays strike upon a spherical concave mirror, they are reflected in a point which lies exactly in the middle, between the mirror and the centre,* C, *of the arc,* PQ. (See the last figure.) This is the case when the rays of the sun strike upon it, which, on account of the great distance of the sun, may be considered as parallel. The point in which these rays are reflected is called the *burning point*, or *focus;* because an indefinite degree of heat may be produced there by the concentration of the sun-beams. *Diverging rays are collected in a point which is as much nearer the focus as the luminous point is remote from the mirror.*

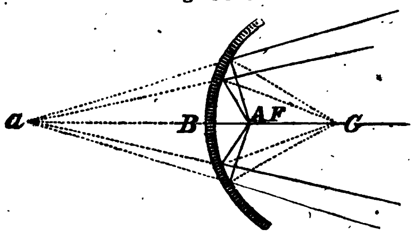
§ 275. The distance of the image from the mirror depends upon the distance of the luminous point before the mirror. With regard to this, we have the following law:—*The nearer the object approaches the focus, the greater will be the distance of the image before the mirror. When the object,* A, *is in the focus itself* (Fig. 135), *then there will be no image at all;* because the rays will then be reflected parallel to one another.

Fig. 135.



Lastly, *when the object,* A, *is between the focus and the mirror* (Fig. 136), *the reflected rays will be diverging, and the image will be behind the mirror,* in a point, *a*, which, to distinguish it from the real focus, before the mirror, is called the *geometrical* or *virtual* focus.

Fig. 136.



§ 276. If MN is a *whole object* before the mirror (Fig. 137), then the image of the point M will be in *m*, in the axis MO (§ 273); and the image of the point N in *n*, in the axis NP; consequently every other point of the object, MN, will have its image *between* *m* and *n*; so that *mn* is the whole image of the object MN.

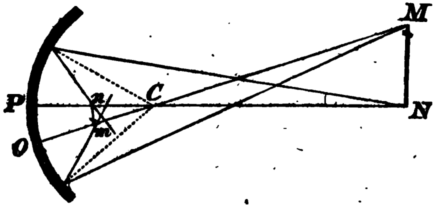


Fig. 137.

§ 277. When the object is further from the mirror than the focus, the image is inverted (as is the case in the last figure); but when the object is between the mirror and the focus, the image will be upright, and grow larger in proportion as the object is placed nearer the mirror.

The truth of these assertions may be proved by simple drawings; observing always to make the angle of incidence, made by the striking ray and the radius of the mirror, equal to the angle of reflection made by the radius and the reflected ray. The whole may be illustrated by the simple experiment of placing the flame of a candle nearer or farther from the focus, or in the focus itself.

§ 278. *Convex Mirrors.* How the image is formed with a convex mirror, may likewise be shown by drawing Fig. 138, whereby it will be easy to perceive, 1st, That the image appears always *upright*, and *behind* the mirror (see the figure); 2d, That it will recede from the mirror, and be smaller in proportion as the

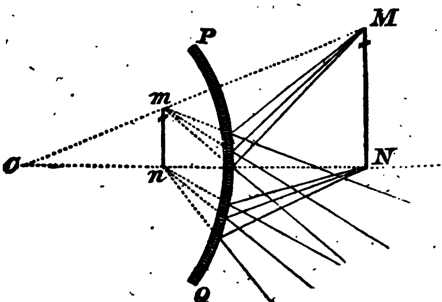


Fig. 138.

object (MN) recedes from it; and, 3dly, That a convex mirror of a smaller radius represents the same object, held at the same distance from it, smaller than one of a greater radius.

All these assertions may be easily verified by experiments with the flame of a candle.

§ 279. *Conical and Cylindrical Mirrors.* What has been said of spherical mirrors, will serve to explain the phenomena of cylindrical and conical mirrors. Both give a perfect image of the object in *length;* but the transversal dimensions appear smaller, and are, in conical mirrors, diminishing from the basis to the vertex of the cone.

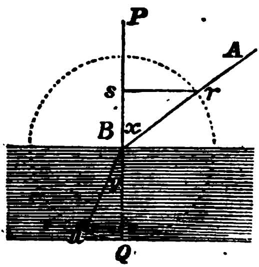
Upon this property of cylindrical and conical mirrors is founded the art of making certain distorted drawings and paintings, which become regular when viewed through such a mirror. They are known by the name of *catoptrical anamorphoses.*

C.—*Refraction of Light.*

1. *General Observations.*

§ 280. *Ratio of Refraction.* It has been observed (§ 266, page 205), that a ray of light, AB, passing from one medium into another, is refracted; and it has been shown, also, by experiments, that the angle of incidence, x, formed by the ray, AB, and the perpendicular, PBQ, bears a certain constant ratio to the angle of refraction, y, made by the same perpendicular, PBQ, with the refracted ray, Bu; that is, a ratio, which, for the same two mediums, remains uniformly the same,* whatever may be the position of the ray with respect to the surface.

Fig. 189.



* Mathematically speaking, this constant ratio does not exist between the angles, but between their *sines*, which are obtained by describing a circle from the centre, B, and dropping from r and u, the perpendiculars rs and uv, to the line, PQ. When the angles are small, then the ratio of their sines may be taken for that of the angles, x and y.

Thus the ratio of the angle of incidence to the angle of refraction is nearly as 4 to 3 between air and water; as 100 to 65 between air and common glass, &c.

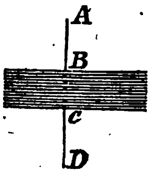
§ 281. *Refracting Power of Bodies.* The smaller the angle of refraction, the greater is said to be the refracting power of the transparent body. In this manner the refracting power of many bodies has been determined. (See Table V., at the end of the book.)

Heretofore a belief existed, that the refracting powers of bodies are in proportion to their densities; but experiments have since proved that the refracting power is greater in *combustible* substances, independently of their densities.

2. *Refraction of Light in a Body bounded by Plane and Parallel Surfaces.*

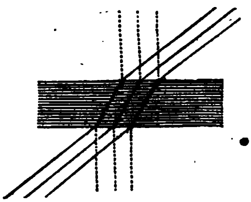
§ 282. When a ray of light falls perpendicularly upon a transparent body, bounded by plane and parallel surfaces, then no refraction takes place, and the emerging part, CD, has yet the same direction as the incidental ray, AB. (See Fig. 140.)

Fig. 140.



§ 283. When parallel rays (Fig. 141) fall obliquely upon a transparent body, bounded as before mentioned, the emerging rays will again be parallel; because, upon entering the body, the rays will be refracted as much towards the perpendiculars, as, upon emerging from it, they are refracted from them.

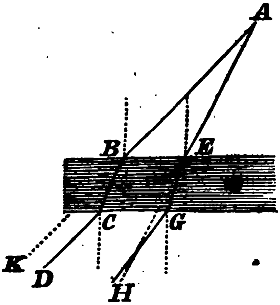
Fig. 141.



If the emerging rays pass through a second or third transparent body, the emerging rays will still be parallel to each other, provided the refracting surfaces are themselves parallel to each other. This is, for instance, the case with the rays of the sun, when refracted through several parallel panes of a window.

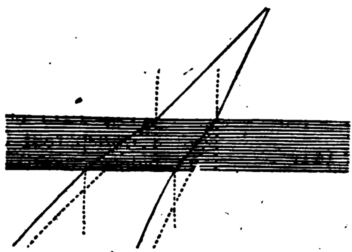
§ 284. When diverging rays fall upon a transparent body of the same description, then the emerging rays, CD,

Fig. 142.



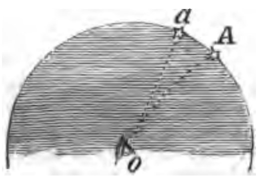
GH, will be less diverging than the incidental rays, ABK, AEH, when the transparent body possesses a greater refracting power than the air, and more diverging when the reverse takes place. (Fig. 142 represents the first case, and Fig. 143 the second.)

Fig. 143.



These principles will serve to explain a variety of phenomena, viz. why, through the refraction of light in the atmosphere, the stars appear higher than they really are; because, the different strata of air becoming more dense in proportion as they approach the surface of the earth, a ray of light, passing through them, is continually refracted, and describes an arc, AO, so that the spectator's

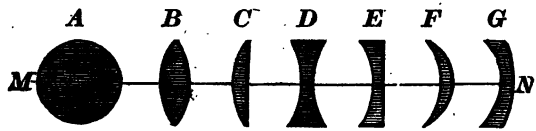
Fig. 144.



eye in O sees the star A in *a* (the distance between A and *a* is termed the *parallax*, and is of the greatest importance in astronomy);—why a body, placed under water, appears nearer the surface;—why a rod, partly immersed in water, appears broken;—why an atmosphere, charged with fog or mist, exhibits different optical deceptions, particularly in the vicinity of lakes, and other large bodies of water (the *fáta mórgana*, near the city of Reggio, in Italy), &c.*

3. *Refraction of Light through Bodies bounded by Spherical Surfaces* (*Lenses*).

§ 285. *Lenses.* A piece of glass, having on one or both sides a spherical form, is called a *lens*.† There are seven different kinds of lenses.



1. A *spherical lens*, A (see the figure), having every point in its surface at the same distance from the common centre.

2. A *double convex lens* (B), bounded by two spherical sections.

3. A *plano-convex lens* (C), bounded by a plane on one side, and a spherical section on the other.

4. A *double concave lens* (D), bounded by two concave spherical sections.

5. A *plano-concave lens* (E), bounded by a plane on one side, and a concave spherical section on the other.

6. A *meniscus* (F), bounded by a concave and a convex spherical surface; the radius of the convex surface being smaller than that of the concave surface.

* Among those who have particularly distinguished themselves in this department of Natural Philosophy, are Dr. Brewster and Dr. Wollaston, in England; Messrs. Biot, Arrago, and Malus, in France; and Tobias Mayer, and Prof. Wünsch, in Germany. See Gilbert's Annals of Nat. Philosophy; Gehler's Dictionary of Nat. Philosophy, newly edited by Dr. Brandes.

† From the Latin *lentil*, a small kind of bean.

7. A *concavo-convex lens* (G), bounded by a concave and convex surface, but the radius of the concave surface being smaller than that of the convex surface.

The line MN, in which the centres of these spherical surfaces are situated, and to which these lenses are perpendicular, is called their *axis*.

§ 286. *Properties of Convex Lenses.—All convex lenses have the following properties :—*

1. Parallel rays (Fig. 145), or rays proceeding from a distant object, A (Fig. 146), are refracted by them in such

Fig. 145.

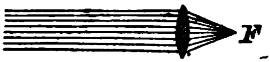
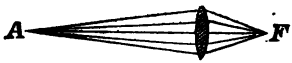


Fig. 146.



a manner, that they unite again in a certain point, F, behind the lens. This point is called the *image* of A. (Compare this to the laws of reflection, page 207.)

2. The image lies always in a straight line, drawn from the object to the centre of the lens. (Compare § 273.) Hence it follows that—

3. The images of the objects before the lens appear behind it, but inverted, as is the case with the image produced by concave mirrors. (§ 276.)

4. When the object is the sun, then the refracted rays meet in a point, which is called the *focus*, or *burning point*, of the lens; because the heat produced in that point by the condensation of the sun-beams is capable of igniting combustible substances.

5. There is a focus, or burning point, on either side of the lens, according as one or the other side is turned towards the sun.

6. The distance of the focus from the lens is called the *focal distance*, and may be found by experiments.

In a double and *equally* convex lens, the focal distance is generally equal to the radius of the sphere. If the lens is unequally convex, the focal distance is found by the following rule :—Multiply the two radii of its sections, and divide twice that product by the sum of the radii ; the quotient is the focal distance required.

7. The nearer an object approaches the one focus of the

lens, the farther will its image fall beyond the focus on the other side.

8. When the object is placed in the focus itself, then there is no image whatever formed on the other side of the lens; because the emerging rays will be parallel to one another. (Compare § 275.) But when—

9. The object approaches still nearer, so as to be between the focus and the lens, then the emerging rays are *diverging*, and seem to proceed from a point *before* the lens, which is called the *focus of the diverging rays*.

Figures 147, 148, and 149, represent the last three cases. When the image is in A (Fig. 147), beyond the focus F, then

Fig. 147.

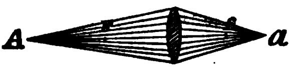
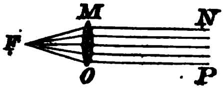
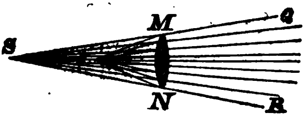


Fig. 148.



the image is in *a*, beyond the focus *f*, on the other side. When the object is in the focus F (Fig. 148), then no image is formed, and the emerging rays MN, OP, are parallel to each other. Finally, when the object is between the focus, F, and the lens

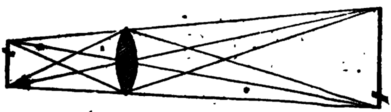
Fig. 149.



(Fig. 149), the emerging rays, MQ, NR, are diverging, and seem to emanate from the point S, before the lens.

10. The farther the image is made to recede from the lens, the more will the object appear *magnified*. Moreover, the image must be *inverted* (Fig. 150), as is the case with the image produced by refraction from a concave mirror.

Fig. 150.



11. The greater the focal distance of the lens, the greater are the images of one and the same object at the same dis-

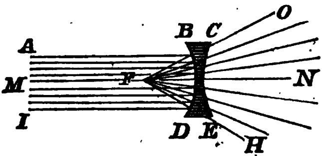
tance from the lens; or, in other words, *the magnifying power of the lens increases with the focal distance.*

All these principles may easily be proved by drawings, or simple experiments with the flame of a candle. Their rigorous demonstration belongs to mathematics.

§ 287. *The phenomena produced by concave lenses are the following :—*

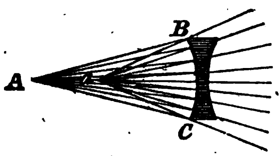
1. When parallel rays, AB, ID (Fig. 151), fall upon a concave lens, the emerging rays, CO, EH, are *diverging*, and seem to proceed from a point, F, which is called the *virtual*, or principal focus of the lens.

Fig. 151.



2. When diverging rays, AB, AC, &c. (Fig. 152), proceeding from any point beyond the focus, fall upon a concave lens, then the emerging rays are still more diverging, and seem to proceed from a point, *a*, between A and the centre of the lens. As the object, A, approaches the lens, the point *a* will also grow nearer it.

Fig. 152.



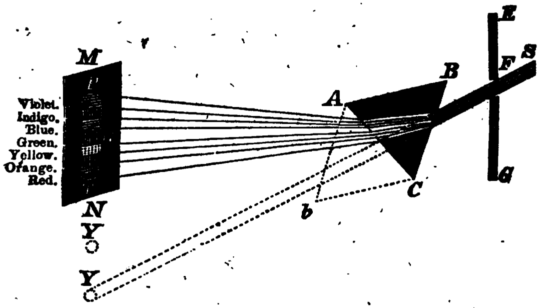
3. Converging rays are either made less converging, or parallel, or even diverging, according as they proceed from a point beyond the focus, or from the focus, or from a point within the focus and the lens. Hence it is evident that concave lenses are unfit for the formation of images; because, to produce an image, the refracted rays must cut each other.

§ 288. The effect of a *meniscus* (§ 285, 6) is the same as that of a *convex* lens of the same focal distance; that of a *concavo-convex* lens is the same as that of a *convex* lens of the same focal distance.

Remark. It is important to distinguish between *dioptric* and *catoptric images*. The images produced by lenses are called *dioptric* images; while those produced by the refraction of light from mirrors are termed *catoptric* images.

D.—*Theory of Colors* (*Achromatics*).

Fig. 153.



§ 289. *Prismatic Spectrum.* When a small opening is made in the window-shutter of a dark room, and a triangular glass prism is placed behind it, in such a manner that the rays of the sun may enter and leave the prism at equal angles, then the rays, after being refracted by the prism, will disperse, and form upon a screen, MN, an oblong image, PT, containing the seven colors which are enumerated in the figure; *the red being least, and the violet most, refracted* from the original direction of the beam of solar light, AB. This oblong image, PT, is called the *solar*, or *prismatic spectrum.*

§ 290. The magnitude of the spectrum varies according to the different substances chosen for the refracting prism. These substances, therefore, are said to possess different *dispersive powers.*

§ 291. *Simple and Compound Colors.* When a hole is made in the screen, MN, opposite any of these colors, and a beam of colored light is let fall separately upon a second prism, it will be found that the light of each of these colors is *alike* refracted; because the second prism cannot separate them again into an oblong image, or into any other colors. For this reason, the above-mentioned seven colors are called *simple*, or *homogeneous;* and the white light, from which they are obtained, is called *compound*, or *heterogeneous.*

§ 292. If the prismatic spectrum is made to fall upon a lens or concave mirror, then the seven colors refracted into the focus appear again *white*, as the solar beam, AB, before being refracted by the prism.

§ 293. Another prism, AC*b* (see the last figure), formed like the prism ABC, and made of the same substance, when placed as represented in the figure, destroys, likewise, the spectrum, PT, by refracting all the rays separated by the prism ABC, to the same point, Y, where, by their mixture, they form again white light.

§ 294. But when the angle of the prism AC*b* is not equal to the angle of the prism ABC, then the second prism does neither correct the refraction of the first, nor prevent the dispersion of the colors, and a short spectrum is formed in Y′, a little *above* Y, when the angle of the prism AC*b* is less than the angle of the prism ABC, or *below* Y, when the angle of the prism AB*b* is greater than that of the prism ABC.

§ 295. From these and other experiments, first made by Sir Isaac Newton,* and afterwards repeated and extended by Euler, Young, Brewster, Dolland, Leslie, Arrago, Biot, Tobias Mayer, Wünsch, &c., we are entitled to the following conclusions :—

1. *That white solar light is compounded of colored rays, and is capable of being decomposed into seven primitive colors.*

2. *That the seven colors have each the same capacity for being refracted, or, in other words, that they have all the same refrangibility.*

3. *That their mixture produces again white light.*

4. *That there is no refraction of light without dispersion of colors.*

5. *That different substances possess different dispersive powers.*

---

* Optics, by Sir Isaac Newton. London, 1701. Optice sive de Reflexionibus, Refractionibus, Inflexionibus, et Coloribus Lucis, Libri III. Auct. Is. Newtono; Lat. redd. Samuel Clarke. Lond. 1706. Leonh. Euleri nova Theoria Lucis et Colorum, in the first volume of his Opusc. varii argumenti.

§ 296. If light (according to Sir Isaac Newton) is *material*, and *emanating* from luminous bodies, then we can explain these phenomena two ways; 1st, by supposing that light is composed of heterogeneous particles, which, by affecting the eyes in various ways, produce the different sensations of colors; or, 2dly, by supposing the particles of light to be homogeneous, but differing from each other in magnitude, and producing different sensations in our eyes, by being propelled with different velocities.

According to Young and Leonhard Euler, who believe light to consist in vibrations similar to those which are productive of sound, the seven simple colors are to the eye what the seven tones of the diatonic scale are to the ear; resulting from the quicker or slower tremulations of the luminous body. White light is, then, for the eye, what a mixture of sounds is for the ear—noise without harmony. The different shades and gradations of the seven simple colors are analogous to the different notes in music.

The phenomena just described explain a number of phenomena in nature:—the appearance of the rainbow, produced by the dispersion of colors, when solar light passes through drops of rain; the colors perceived in a soap-bubble; the colored fringe seen when looking through a cut glass, &c.

Herschel, a celebrated English philosopher, pretends to have discovered invisible rays of solar light, beyond the red color of the spectrum, possessing a greater degree of *heat* than any of the colors of the spectrum. Other experiments, however, made by Beckman, in Carlsruhe, and Leslie, in Edinburgh, do not seem to corroborate this statement.

§ 297. It is important to observe the difference between refraction of light and dispersion of colors; for a certain transparent medium may refract light more than another, and yet have a less dispersive power. Upon this principle is founded the construction of achromatic prisms and lenses, which refract light without decomposing it into colors.

John Dolland, of England, first found by experiment, that flint-glass (the white glass of which drinking glasses are made), and crown glass (the glass with which windows are glazed), have different dispersive powers. By combining flint and crown glass in a lens (as is shown in Fig. 154, where AB represents a concave lens of crown glass, and *ab* a convex lens of flint glass), the dispersive power of the flint lens corrects, to a considerable degree, that of the crown lens. By a concave lens of muriatic acid, with

Fig. 154.

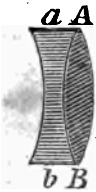


Fig. 155.

a metallic solution, between two lenses of glass (Fig. 155), the rays of different colors are bent from their rectilinear course, with nearly the same regularity as by the reflection from metallic mirrors. This is an invention of Dr. Blair's.*

§ 298. *Variety of Colors.* It remains for us to explain the infinite variety of colors exhibited by different bodies, when exposed to solar light, or the rays of any other luminous substance. This may be explained, according to Sir Isaac Newton's theory, by supposing these bodies to possess different chemical properties, in consequence of which they decompose the white solar light, absorbing some of its simple colors, and reflecting the rest. Were we to adhere to Euler's theory, we should have to seek the reason of the variety of colors in the shape and elasticity of the surface which is presented to the light; for on these would depend the angle of refraction, and the quickness of the vibrations of the refracted colors.

§ 299. Some bodies suffer part of the light to which they are exposed to pass through them, and absorb or reflect the rest. This property explains the blue hue of the atmosphere (because the air reflects only the blue color, and lets the rest pass through it), the effect of colored glasses, &c.† Other bodies become transparent when their pores

* Euler proved the possibility of combining two substances whose dispersive powers might mutually correct each other, long before the experiments of Dolland, by the simple force of mathematical reasoning. (See Euler's Dioptrica.)

† Goethe, in his Achromatics (Goethe's Farbenlehre, Tübingen, 1810), explains the variety of colors in a manner diametrically opposite to that of Sir Isaac Newton. But his work is better adapted to painters and artists, as the whole subject is treated in particular reference to the fine arts.

are filled with a transparent fluid. Paper becomes transparent when it absorbs a quantity of oil; the stone called *hydrophane*, when dipped in water, &c.

§ 300. The chemical properties of bodies may be so changed, that they act differently upon light from what they did before. In this case, they must also exhibit a different color. Instances of this kind are daily furnished in chemistry. We may also cover the surface of a body with a substance (pigment) which operates differently upon light, and thereby produces a change of color. Hereupon depends the process of dyeing, painting, &c.

E.—*Of Vision.*

1. *The Eye.*

§ 301. The human eye (of which Fig. 156 is a front view, and Fig. 157 a vertical section) is nearly of a globular form, with a slight elongation or projection in front. It consists of four coats, or membranes—the *sclerotic*, the *cornea*, the *choroid*, and the *retina;* of two fluids—the *aqueous* and the *vitreous;* and of the *crystalline lens*.

Fig. 156.

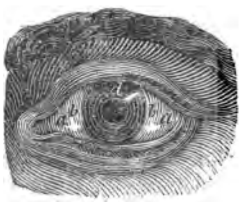
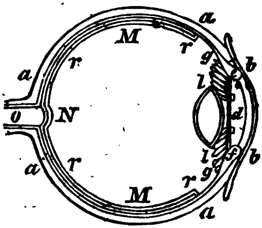


Fig. 157.



§ 302. The sclerotic coat, *aaaa* (Figs. 156 and 157), is the outer and strongest coat (commonly called the *white of the eye*), to which are attached the muscles for giving it motion. Joined to it is the *cornea*, *bb*, which is the clear and transparent membrane through which we see. The

cornea consists of several layers, to give it strength, and to defend the delicate part within from external injury. On the inner surface of the sclerotic coat is the choroid coat, covered with a black pigment. The innermost coat is the retina, *rrrr*, formed from the expansion of the optic nerve, which enters the eye at *o*. In the centre of the retina is a small hole, with a yellow margin; properly speaking, it is but a transparent spot, free of the pulpy matter of which the retina consists.

§ 303. The interior part of the globe of the eye is divided into two very unequal segments, by a flat, circular membrane, *ef*, called the *iris*. It is of different colors in different persons; and we are in the habit of calling a person *black-eyed*, *blue-eyed*, &c. according as the iris of his eyes is black, blue, &c. The iris has a circular opening, *d* (Figs. 156 and 157), in its centre, called the *pupil*, which expands when the light which enters through it is diminished, and contracts when the light is increased. The space before the iris, which is called the *anterior chamber of the eye*, contains the aqueous humor, so called from its resemblance to pure water; and the space behind the iris is called the *posterior* chamber, and contains the *crystalline lens*, *ll*, and the *vitreous humor*, which fills all the rest of the eye.

§ 304. The crystalline lens is suspended in a transparent *capsule*, or *bag*, by what are called the *ciliary processes*, *gg*. This lens is more convex behind than in front (as shown in the figure), and consists of concentric coats, which are again composed of fibres. The lens is destined to convey the rays, after refraction, to the retina, there to form the image of the object before the eye. The *vitreous humor*, MMN, which occupies the largest portion of the eye, lies immediately behind the crystalline lens, and fills the whole space between it and the retina, *rrrr*.*

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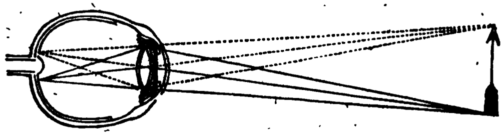
* The above description of the eye is chiefly taken from the excellent treatise on optics, in the Library of Useful Knowledge. Those teachers who wish for a more detailed description of the eye, and the functions of each of its membranes, will find it in the first volume of Caldwell's translation of Blumenbach's Physiology; Sect. XXI., on Vision. Philadelphia, 1795.

For a more minute description of the crystalline lens, and its muscular properties, see Prof. Reil's Dissertation, in Gren's Journal of Natural Philosophy; Vol. VIII., page 325.

2. *Vision.*

§ 305. The crystalline lens and the retina are by far the most important parts of the eye; and on them depends chiefly the process of seeing. The rays of light which enter the eye through the pupil, after being refracted through the crystalline lens, and the other aqueous and vitreous humors of the eye, impress the retina with a distinct image of the object before the eye (Fig. 158), in a manner similar to the

Fig. 158.



formation of images by convex lenses. (§ 286, page 214.) We see an object the clearer the more distinctly the retina is impressed with its image.

§ 306. The different humors of the eye seem to be destined to correct the dispersion of colors by the crystalline lens; otherwise we should see all things embroidered with colors and fringes; as they appear when seen through a prism.

§ 307. The eye cannot see clearly a distant object and a near one at the same time; because the image of the more remote object will be nearer the crystalline lens than that of the object which is at a shorter distance (§ 214, page 286, 7thly); consequently, when the image of the one is distinct on the retina, that of the other will be less so.

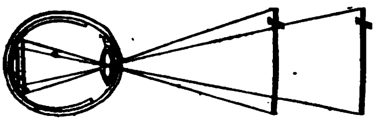
§ 308. Some persons cannot see well at a distance, while others cannot see clearly an object which is near them. The former are called *near-sighted*, and the latter *long-sighted*. In a near-sighted person, the image of a distant object falls always between the retina and the crystalline lens; in a far-sighted person, the image of a *near* object falls *beyond* the retina. Hence the invention and use of *spectacles*. Near-sighted persons need concave glasses,

far-sighted persons use convex glasses, to produce a distinct image on the retina, because the image is by the former brought nearer, and by the latter farther from the glass; so that, in each case, it falls on the retina.

§ 309. The images of the objects before the eye appear inverted on the retina. (§ 286, 3dly.) Several images, however, have, with regard to each other, *the same relative position* which the objects themselves have; and this is the reason why we do not *see* them inverted. We do not even become conscious of this inversion of the images upon the retina, and do not judge, from the position of the image in the eye, of what is above or below, to the right or left of an object.*

§ 310. Two lines (Fig. 159), drawn from the two extremities of an object to the middle of the crystalline lens, form what is called the *visual angle*, and the image of the object itself is formed upon the retina, within the extended legs of this angle. The greater the angle is, the greater is the image on the retina; the greater, therefore, *appears* the object itself. When the visual angle is very small, then the object, which appears to diminish to a simple point, can no longer be perceived, unless it be very intensely illumined. This is the case with the fixed stars, which we cannot perceive in daylight.

Fig. 159.



§ 311. The farther an object is from the eye, the smaller is the visual angle. (See the last figure.) Of the distance itself, however, we do not become conscious by mere vision.

On the contrary, we know that children, and persons who have had cataracts removed, had no idea of distance, but had to ac-

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* This is a matter of physiological speculation. The eye seems to be merely the medium through which the optic nerve receives impressions from the objects before the eye. But in what manner the optic nerve propagates these impressions through the brain, and how thence the mind itself becomes conscious of them, is totally unknown to the anatomist and the physiologist.

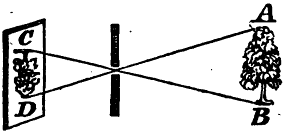
quire it by experience. Thus we judge of the distance of an object by comparing its apparent magnitude to its known size; by the weakness or intensity of the light in which it appears; by the number of things which are seen between the object and the eye.

F.—*Optical Instruments.*

§ 312. *The following are some of the principal instruments now in use:—*

1. The *camera obscura*, or *darkened chamber.* If, through the window-shutter of a darkened room, a small circular hole be made, and provided with a double convex lens, the images of external objects, such as trees, houses, men, &c., will be seen upon a screen, or piece of white paper, placed before the aperture.

Fig. 160.



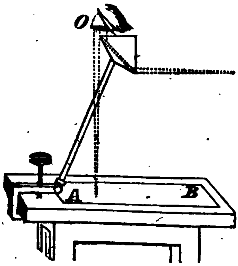
The same phenomenon may be witnessed, also, without a lens; but then the colors will be less bright. The images appear inverted (see the figure), because the rays which proceed from the top, A, of the object, will fall upon D, the foot of the image; whereas, the ray BC, proceeding from the foot of the object, will form the top of the image.

Fig. 161.

Another modification of the same instrument, which is frequently used by painters, to delineate a landscape, may be seen from the following figure. It consists of a small house, with a plane reflector, inclined at 45 degrees with the horizon, and a plano-concave lens (see Fig. 161), through which the rays, reflected from the mirror, are so refracted as to form a perfect image of the object without, upon a piece of paper, upon which the painter may sketch it. The utility of this instrument is manifest from its construction.

2. The *camera lucida*, invented by Dr. Wollaston. It consists in a quadrangular prism (Fig. 162), attached to a small metallic rod, which may receive any inclination you please, with the table to which it is fixed. The rays proceeding from a distant object are refracted by a prism, in such a manner, that, to an eye in O, the image appears upright on the horizontal table, AB. This instrument may likewise be used for delineating a landscape.

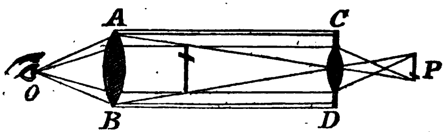
Fig. 162.



3. The *single microscope*. This consists in a double convex lens, or in a small globe of glass, made by melting the ends of a few threads of spun glass in the flame of a candle. Its magnifying effect, when held between the object and the eye, may easily be understood, from the properties of convex lenses.

4. The *compound microscope*. It is composed of two lenses (Fig. 163), fixed in a tube, ABCD, in such a way

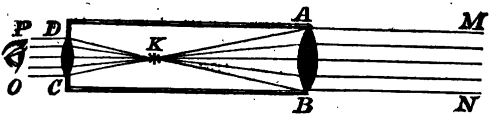
Fig. 163.



that an image of the object, P, is formed within the tube, and afterwards seen magnified through the other lens, AB. The object is commonly placed a little beyond the focus of the smaller lens, CD, which is called the *object-glass;* the lens AB is called the *eye-glass*.

5. The *astronomical telescope*. This consists of two convex lenses, of unequal focal lengths (§ 286, 6th), placed at a distance from each other, equal to the sum of their focal lengths. The lens of greater focal length forms the object-glass; the other lens forms the eye-glass. The rays, MA, NB, which come from a very distant object, for instance,

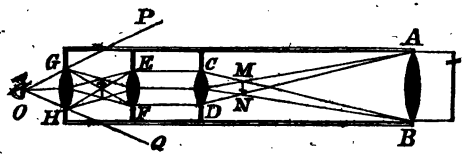
Fig. 164.



from a star (and which may, therefore, be considered as parallel to each other), are by the object-glass collected into an image, K. This image is then seen as many times magnified through the eye-glass, DC, as the focal length of this eye-glass is contained in the focal length of the object-glass. Thus, if the focal length of the eye-glass, DC, be 100 times contained in that of the object-glass, AB, the star will be seen 100 times magnified. That the object is seen inverted, is easily perceived from the figure. The ray AM will, after refraction, be seen in the direction CO, and the ray NB, in the direction DP; but this circumstance is of no consequence in astronomical researches.

6. The *terrestrial telescope*, for such purposes as ship and spy-glasses. This is a refracting telescope, with two addi-

Fig. 165.



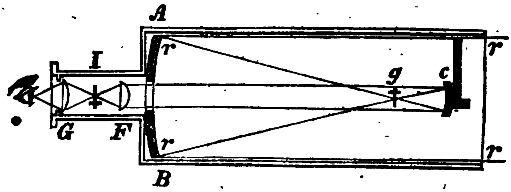
tional eye-glasses of the same size and shape, placed at equal distances from each other, and in such a manner that the focus of the one meets that of the next lens. The two additional eye-glasses, EF, GH, are introduced for the purpose of collecting the rays proceeding from the inverted image, MN, into a new, upright image, between GH and EF, which is then seen through the last eye-glass, GH, under the visual angle, POQ.

The image of the object, seen through a refracting telescope, is never so clear and perfect as that obtained by the reflecting telescope (first projected by Kepler); because the dispersion of

colors, which every lens more or less produces, renders the image dull and indistinct, in proportion to the number of lenses employed.

7. The *reflecting telescope*. (Fig. 166.) It consists of a

Fig. 166.



large tube, containing two concave metallic *mirrors*, AB, and *c*, with two plano-convex eye-glasses. The mirrors are placed at a little more than the sum of their focal distance from each other. The effect produced by it is this: The parallel rays, *rr*, *rr*, coming from a distant object, are, by the mirror AB, reflected to a focus, *g*, where an inverted image of the object is formed. The diverging rays proceeding from this image are, by the small mirror, *c*, again reflected, and received, by the eye-glass, F, through a hole in the middle of the mirror, AB. The eye-glass F collects these reflected rays into a new image, and this image, which is now upright, is seen magnified, through the second eye-glass, G.

The reflecting telescope, just described, was invented by Dr. Gregory. Its advantage over a refracting telescope is considerable; because, admitting of an eye-glass of a shorter focal distance, an object may be seen through it much more magnified; and as, in the reflection from the mirrors, there is no dispersion of colors, the image is by far more distinct than it can ever be produced by the best combination of lenses. Besides the telescope just described, there are others, varying a little from it in their construction. Gregory's telescope, however, is most frequently used for astronomical purposes.*

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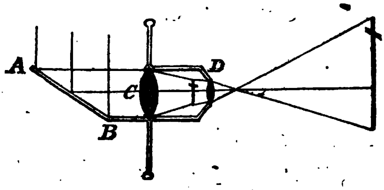
* The most remarkable reflecting telescopes, besides the Gregorian, are Sir Isaac Newton's telescope, the Cassegranian reflector, and Herschel's large telescope, now at Greenwich, in England. For a minute description of these instruments, see Library of Useful Knowledge, treatise on Optical Instruments; Part I. pages 11—19.

8. The *solar microscope*. This consists of two lenses, C and D (Fig. 167), and a plane mirror, AB. The two lenses are contained in a tube, which is fixed in such a manner to one of the window-shutters of a darkened room, that the only light which enters the room passes through the lens C. This lens is called the *condenser*. The mirror, AB, remaining without, and the condenser, C, are destined to throw the greatest possible light on the object, which is placed a little beyond the focus of the lens C. The rays which depart from this object are refracted by the convex lens D, and form behind it a magnified image, whose dimensions are the greater the nearer the object approaches the principal focus of the lens C. This image is received upon a screen, as in the camera obscura.

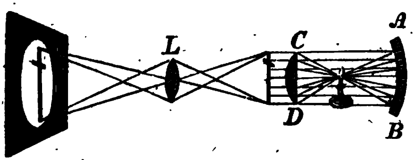
Fig. 167.



The solar microscope serves to magnify little insects, animalculæ of infusion, &c.; but the most beautiful experiment that can be made with it, is to witness the formation of crystals, when, instead of the object, a solution of sulphate of soda is placed near the principal focus. In a few minutes the liquid evaporates, and the process of crystallization may be followed in all its details.* Any other saline solution will produce a similar effect.

9. The *magic lantern*, which is constructed on the same principle as the solar microscope. But, instead of the light of the sun, the flame of a candle, or some other luminous body, is used. When this light is, of itself, not intense enough, a concave mirror, AB (Fig. 168), is substituted for the plane mirror (in the last

Fig. 168.



* See Biot's Précis Elementaire de Physique; Tom. II. page 358.

figure), and a lens, CD, is used for a condenser. The effect is the same as that produced by the solar microscope, only proportionally weaker, as may be supposed from the less intense illumination of the object.

RECAPITULATION.

Of Light.

[§ 257.] What opinions have been entertained by philosophers respecting the nature and propagation of light?

[§ 258.] What do you call the sensations which luminous bodies produce in our eyes? What do we, by these, become conscious of?

[§ 259.] What are all bodies, with regard to light, divided into?

What are the principal luminous bodies? What other means are there of producing light?

[§ 260] When does a dark body become visible? What is the light thus received called?

[§ 261.] When do you call a body *transparent* or *pellucid?* What bodies do you call *opaque?*

What substances are generally pellucid or transparent?

[§ 262.] What are *light-magnets*, or *absorbers of light?* Give instances of such bodies.

[§ 263.] Is all the light which falls upon dark bodies reflected by them? What do you call those bodies which absorb light most? What those which reflect it most?

[§ 264.] *How is light propagated? With what velocity?*

How can you prove that light is propagated in straight lines? How has the velocity of light been ascertained? Can the velocity with which light moves upon our globe be measured? Why not?

[§ 265.] If light is propagated in straight lines, in what proportion must its intensity decrease?

On what principle is this law established?

[§ 266.] What do you understand by the term '*refraction of light*'?

By what simple experiment can you illustrate this principle?

[§ 267.] How is light affected when passing near the surface, edges, or corners of bodies? What is light in this case said to be?

What does this phenomenon seem to prove?

[§ 268.] What takes place when light falls upon an opaque body? Upon what does the magnitude, shape, and position of the shade which an opaque body casts behind it, depend?

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1. *Reflection of Light.*

[§ 269.] *When a ray of light strikes upon a polished surface, either plane or curved, what law does it follow?*

[§ 270.] What are those bodies which are commonly used to reflect light called? When do you call a mirror *plane*, *convex*, or *concave*?

What are the best reflectors? Why must glass mirrors be quicksilvered on one side?

A.—*Reflection of Light from Plane Mirrors.*

[§ 271.] *How does a luminous point before the mirror appear to the eye?*

How can you prove this?

[§ 272.] What is the point behind the mirror, from which the rays of light seem to proceed, called? Does the law which you have just found for a luminous point, equally apply to a whole object? *How, then, will a whole object before the mirror appear to the eye?*

B.—*Reflection of Light from Spherical Mirrors.*

[§ 273.] *What is the principal law with regard to an image produced by a luminous point before a spherical concave mirror?* What is the name of a straight line drawn from the luminous point through the centre of the arc of which the mirror makes a part?

How can you prove the correctness of this law by a diagram?

[§ 274.] *How are parallel rays reflected from a concave mirror?* When does this take place? What is the point to which the rays of the sun are reflected from a concave mirror called? Why does it receive this name? What law is there with regard to diverging rays?

[§ 275.] On what does the distance of the image from the mirror depend? *What law can you lay down respecting it?*

(The elder pupils may here be required to draw Figs. 135 and 136, page 208.)

[§ 276.] Does the law, which you have just found with regard to a luminous point, equally apply to a whole object? Show me this by a figure.

[§ 277.] In what case will the image of the object be inverted? In what case will it be upright?

[§ 278.] How is the image produced by reflection from convex mirrors situated with regard to the object? Which of two convex mirrors represents the same object, held at the same distance from it, larger than the other?

[§ 279.] How can you explain the phenomena of cylindrical and conical mirrors? In what direction do these mirrors give the correct dimensions of the object? How do the transversal dimensions of the object appear through them?

C. *Refraction of Light.*

1. *General Observations.*

[§ 280.] When a beam of light passes from one medium into another, what relation does the angle of incidence bear to the angle of refraction?

What is the ratio of the angle of incidence to the angle of refraction between air and water?

[§ 281.] What relation exists between the angle of refraction and the refracting power of the transparent body?

What belief has heretofore existed, with regard to the refracting power of bodies? What have modern experiments proved on this subject?

2. *Refraction of Light in a Body bounded by Plane and Parallel Surfaces.*

[§ 282.] What takes place when a ray of light falls *perpendicularly* upon a transparent body bounded by plane and parallel surfaces?

[§ 283.] What takes place when parallel rays fall *obliquely* upon a transparent body?

If the emerging rays pass through a second and third transparent body, how will the rays then be situated with regard to each other? Give instances of this kind.

[§ 284.] What takes place when diverging rays fall upon a transparent body, bounded as before?

(The elder pupils may here be required to draw Figs. 142 and 143, page 212.)

What phenomena can you explain from the principles which you have just advanced?

3. *Refraction of Light through Bodies bounded by Spherical Surfaces (Lenses).*

[§ 285.] What do you call a piece of glass, having on one or both sides a spherical form? How many different kinds of lenses are there? What are they?

[§ 286.] What are the principal properties of convex lenses?

[§ 287.] What are the phenomena produced by concave lenses?

[§ 288.] What are the effects produced by a meniscus, or a concavo-convex lens, similar to?

D.—*Theory of Colors.*

[§ 289.] What do you understand by the solar or prismatic spectrum? By what means is it obtained?

[§ 290.] Is the magnitude of the spectrum the same, whatever be the substance chosen for the prism? What are these substances, therefore, said to possess?

[§ 291.] When the light of each color of the spectrum is separately let fall upon a second prism, is there any difference found in the degree of refraction of the seven colors? Why is there none? What are the above-mentioned seven colors on this account called? What is the white light from which they are obtained called?

[§ 292.] What takes place when the prismatic spectrum is made to fall upon a lens or concave mirror, by which they are refracted into a focus?

[§ 293.] What takes place when another prism, formed like the first, and made of the same substance, is brought in contact with the former?

[§ 294.] What takes place when the angle of the second prism is not equal to the angle of the first prism?

[§ 295.] *To what conclusions do the experiments you have just described entitle you?*

By whom were these experiments first made?

[§ 296.] In how many different ways can you explain these phenomena, according to the theory of Sir Isaac Newton? How can you explain the same phenomena, according to the theory of Young and Leonhard Euler?

What phenomena in nature are explained from those you have just described?

[§ 297.] Is it possible for a certain medium to refract light more than another, and yet to have a less dispersive power? What optical instruments are constructed upon this principle?

What celebrated English optician first discovered that flint and crown glass have different dispersive powers? What do you call flint glass? What, crown glass? In what manner must flint and crown glass be combined together, in order that the dispersive power of the flint glass may correct that of the crown glass?

What other means is there for bending the rays of different colors with great regularity, and without dispersion from their rectilinear course?

[§ 298.] How can you explain the infinite variety of colors exhibited by different bodies, when exposed to solar light, according to Sir Isaac Newton's theory? How can you explain them according to Euler's theory?

[§ 299.] What property, possessed by some bodies, explains the blue hue of the atmosphere, the effect of colored glasses, &c.? By what other means can you render bodies transparent? When does the stone called *hydrophane* become transparent?

[§ 300.] What must take place when the chemical properties of a body are so changed, that it affects light differently from what it did before? By what other means can you change the color of bodies? What processes in the mechanic arts depend upon this principle?

E.—*Of Vision.*

1. *The Eye.*

[§ 301.] What is the form of the human eye? Of how many coats or membranes does it principally consist? What are these?

[§ 302.] Where is the sclerotic coat situated? Where the cornea? Of what does the cornea consist? What is it intended for? Where is the choroid coat situated? With what is it covered? Where is the retina situated? What is the centre of the retina?

[§ 303.] How is the interior part of the globe of the eye divided? What is the iris? What is the pupil of the eye? When does the pupil expand itself? When does it contract? What does the space before the iris, or the anterior chamber of the eye, contain? What is the space behind the iris called? What does it contain?

[§ 304.] How is the crystalline lens suspended? How is this lens shaped? Of what does it consist? What is this lens destined for? Where is the vitreous humor situated?

2. *Vision.*

[§ 305.] What are the most important parts of the eye? How is the retina impressed with the image of the object before the eye? On what depends the clearness of sight?

[§ 306.] What are the different humors of the eye destined for? How would we see all things, without these humors?

[§ 307.] Can the eye see clearly a distant object and a near one at the same time? Why not? What, then, will always take place?

[§ 308.] When do you call a person *near-sighted?* when *long-sighted?* Where, in a near-sighted person, is the image of a distant object situated? What is its situation in a long-sighted person? What kind of spectacles are suited to near-sighted persons? What kind are suited to long-sighted persons?

[§ 309.] How do the images of the objects before the eye appear on the retina? Does this alter the relative position of these images? Why not? Do we become conscious of this inversion of the images?

[§ 310.] What do you understand by the *visual angle?* What relation does the image on the retina, and consequently, also, the appearance of the object itself, bear to this visual angle? When does an object become invisible? When the visual angle is very small, what is necessary, in order that we may see the object? Give an instance of this kind.

[§ 311.] What relation does the distance of the object bear to the magnitude of the visual angle? Do we become conscious of the distance of an object by mere vision?

Give instances of this kind. How, then, do we judge of the distance of an object?

F.—*Optical Instruments.*

[§ 312.] What are the names of the principal optical instruments now in use? Describe the *camera-obscura*, or *darkened chamber*. Describe a modification of the same instrument, used by painters to delineate landscapes. De-

scribe the *camera lucida*, invented by Dr. Wollaston. What does the *single microscope* consist of? How is the *compound microscope* constructed? Describe the *astronomical telescope; the terrestrial telescope.* What does the *reflecting telescope* consist of?

By whom was the reflecting telescope, which you have just described, invented? Wherein consists the advantage of the reflecting telescope over the refracting telescope?

What is the construction of the solar microscope? What are the uses of the solar microscope? How is the magic lantern constructed?

CHAPTER IX.

OF ELECTRICITY.

PHENOMENA.

§ 313. When a piece of sealing-wax, or a smooth surface of glass, is briskly rubbed with a dry woollen cloth, and immediately afterwards held towards light and small bodies, such as pieces of paper, thread, cork, feathers, &c., these bodies will first fly to the surface which has thus been rubbed, and adhere to it for a short time, after which they are repelled again. But as soon as they have touched the table, they are again attracted, and this process continues for a considerable time. This property, which some bodies acquire by being rubbed, is called *electric attraction* and *repulsion;* the surface which acquires this attractive and repulsive power is said to be *excited;* the bodies themselves, which produce these phenomena, are called *electrics;* and the agent or cause, to which we ascribe these phenomena, is termed *electricity.**

The principal electrics are amber, glass, resin, sealing-wax, the fur of most quadrupeds, feathers, dry air, dry wood, paper, silk, and perfect ice, at 13 degrees below zero of Fahrenheit's thermometer. Most bodies exhibit more or less the same phenomena, under favorable circumstances; wherefore the division of bodies into *electrics* and *non-electrics* is hardly any longer practicable.†

§ 314. If the experiment just described is performed in a dark room, flashes of light, of a bluish color, are perceived,

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* From the Greek word *electron* (amber); because the ancients knew this property of amber.

† The science of electricity is of modern date, and but of the seventeenth century. William Gilbert, Otto von Quericke, Robert Boyle, Hauksbee, Gray, Du Fay, and Franklin, have most contributed to its advancement.

during the friction, extending over the whole surface rubbed, and sparks, attended with a snapping sound, are seen to dart around it in all directions. If a round metallic ball, or a knuckle, be presented to the surface, a spark will be drawn, accompanied by a prickling sensation; and if the face be brought near, a feeling will be excited in the skin, as if it were covered with a cobweb.

§ 315. *Electricity by Induction and Transfer.* When a metallic tube, perfectly round on all sides, and either suspended by silk cords, or supported by a piece of glass or sealing-wax, is brought near, or in contact with, an excited surface, then the whole of that tube will exhibit the same phenomena as the excited surface itself, and is, therefore, in the first case, said to be electrified *by induction;* or, in the second case, *by a transfer of electricity from the excited surface.* But when glass, silk, or sealing-wax, are in the same manner brought near, or in contact with, the excited surface, they exhibit no such influence.

§ 316. *Conductors and Non-Conductors.* From this and similar experiments, we are led to infer that some bodies readily receive and convey electricity, while there are others which seem to possess no such conducting power. The former are called *conductors* of electricity, and the latter *non-conductors.*

The principal conductors of electricity are the metals, water, and the human body. The principal non-conductors are glass, resin, silk, and sealing-wax.

§ 317. *Insulation.* When a body which is capable of conducting electricity, is on all sides surrounded by non-conductors, it is said to be *insulated.*

The great difference between a conductor and a non-conductor consists chiefly in this: When an insulated conductor touches an excited surface, its whole surface becomes electric; and when, in this state, it is again touched by a non-insulated conductor, it loses at once its electricity. A non-conductor, on the contrary, shows the electric phenomena only in the point which has been touched by the excited surface; and when electrified by rubbing, and touched by a conductor, it loses its electricity only in the point of contact.

§ 318. *Electrics and Non-Electrics.* It is important to observe, that all electrics are non-conductors, and that, on

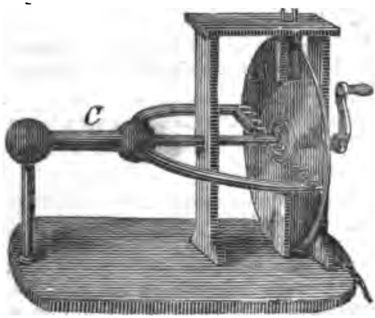
the contrary, the best conductors are non-electrics; or, in other words, that the power of producing electricity increases in all bodies in proportion as their power of conveying this influence diminishes, and *vice versa.*

§ 319. When a metallic body is insulated, and becomes electrified by transfer from an excited surface, its electricity is for a considerable time permanent; but when it is touched with the hand, or brought in contact with conducting bodies, which communicate with the earth, then its electricity is lost by diffusion into the mass of the earth, which is an inexhaustible source for the absorption and supply of electricity.

§ 320. *Proper Shape for retaining Electricity.* In order that a body shall contain electricity for a considerable time, it is necessary that its form should be, as nearly as possible, spherical (a sphere, a spheroid, or a cylinder terminated on both sides by a hemisphere); for it has been found by experiments, that electricity escapes most readily from bodies of a pointed figure, in proportion as the points project from the surface.

§ 321. *Electrical Machine.* To perform electric experiments with greater ease and facility, we make use of what is called an *electrical machine.* It consists chiefly of four parts, viz. the *electric*, the *rubber*, the *conductor*, and the *insulator.*

Fig. 169.



The best machine for this purpose consists of a circular glass plate, A,* turning on an axis. (See the figure.) It is rubbed by two pair of cushions, fixed at opposite parts of the circumference, by elastic frames of wood. A hollow brass tube, C (the prime conductor), supported

* See Biot's Traité de Physique. Tome I. page 545.

by glass columns (the insulators), is fixed to the machine in such a manner, that its branched extremities, which are commonly furnished with pointed wire, nearly meet the plate.

§ 322. *Single Spark—Striking Distance.* By means of this machine, the above-described electrical phenomena may be witnessed much more distinctly than by rubbing the electric with the hand. If a round conductor, or the knuckle, is presented to the conductor of the machine, a vivid spark proceeds from it, which is called the *single spark.* The greatest distance at which this spark may be drawn, is called the *striking distance* of the machine.

To produce these phenomena to their fullest extent, it is necessary that the rubber should communicate with the earth. Very near the conductor, the sparks are smaller than at a greater distance from it.

OPPOSITE ELECTRICITY.

§ 323. *Opposite Electricity.* For the discovery of opposite electricity we are indebted to Du Fay. It is established on the following phenomena and experiments :—

1. If a glass tube and a piece of sealing-wax are both suspended by silk cords, and an excited surface (for instance, a piece of rubbed glass), is presented to them, then this surface attracts both the suspended glass tube and the sealing-wax. The same takes place when the excited surface is a piece of sealing-wax.

2. When the suspended sealing-wax and glass tube are themselves *electrified*, and a rubbed piece of glass is presented to each of them, as before, then the electrified sealing-wax is attracted by it, and the electrified glass tube is repelled.

3. But if an excited piece of sealing-wax is used instead of the excited piece of glass, then the electrified glass tube will be attracted, and the electrified sealing-wax will be repelled.

§ 324. *Laws of Opposite Electricity.* These experiments establish the following laws :—

1. *An unelectrified body is always attracted by an excited electric, whatever be its nature.*

2. The electricity produced by rubbing a piece of sealing-wax is essentially different from that produced by rubbing a piece of glass; and such is the nature of these two kinds of electricity, *that bodies under the influence of the same electricity repel each other, while those acted upon by different electricities evince a mutual attraction.*

§ 325. *Positive and Negative Electricity.* To distinguish these two kinds of electricity, Du Fay called that which is excited by rubbing glass the *vitreous* or *positive electricity;* and that which is produced by rubbing a piece of sealing-wax, the *resinous* or *negative electricity.* If we denote the vitreous electricity by + E, and the resinous electricity by — E, we shall have the following table:—

+ E repels + E.
— E repels — E.
+ E attracts — E.
— E attracts + E.

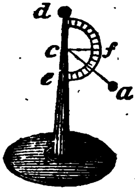
When the rubber of an electrical machine is also provided with a conductor, then this conductor exhibits the phenomena of resinous electricity, or — E; and the prime conductor exhibits those of the vitreous electricity, or + E.

§ 326. This law holds, not only of excited electricity, but also of that which is transferred from an excited surface to another body.

This may be shown by two little pith-balls. When both receive + E, or both — E, from an excited surface, they will, in both cases, repel each other. But when the one receives + E, and the other — E, then they attract each other. (For the purpose of performing this experiment, the pith-balls had better be suspended by flax or silk cords.)

§ 327. *Electrometer and Electroscopes.* Upon the repulsive power which one electrified body exercises upon another, which is under the influence of the same electricity, is founded the construction of electrometers or electroscopes. These are instruments for measuring or indicating the degree of electricity with which a body is charged.

Fig. 170.



One of the simplest contrivances of this kind is Henley's electrometer (Fig. 170); but it is by no means an exact measurer of electricity. It consists of a slender rod of light wood, capable of revolving round its axis, *c*, and terminating in a small pith-ball, *a*; this rod is the index of the instrument; *dfe* is an ivory semicircle, for the purpose of showing the degree of elevation of the movable index, *ca*. The whole is fixed to a wooden stem, which may be fitted to a hole in the upper surface of the conductor of an electrical machine. The number of degrees described by the movable index is then the evidence of the quantity of electricity with which the apparatus is charged.

The repulsive and attractive power between the two kinds of electricity is also taken advantage of in some electric toys, such as the dancing of small figures, cut out of paper or corkwood, between two metallic plates, of which one communicates with the earth, and the other with the conductor of the machine—the flying feather, the electrical spider, &c.

§ 328. When a piece of metal, shaped in the form of an S, and pointed at both ends, is placed upon a pointed wire, which communicates with either of the conductors of an electrical machine, then it will move round with great velocity while the machine is turning. If the experiment is performed in the dark, then a circle of light is seen, and a current of air is felt to proceed from the points of the metal; which, however, is generally noticed when electricity escapes from a pointed surface.

THEORY OF ELECTRICITY.

§ 329. To explain the above-described phenomena of electricity, two theories have been established; one by Du Fay, and the other by Dr. Franklin.

I. According to Du Fay's theory, there exist two very subtile and highly-elastic fluids, which pervade the earth and all bodies, but are void of any perceptible degree of gravity. These two fluids possess the following properties:—

a. They move with various degrees of facility through

different substances: in conductors, or non-electrics, such as metals, the human body, &c., without the least perceptible obstruction; but in non-conductors, or electrics, such as glass, resin, &c., they move apparently with great difficulty.

b. Both fluids possess the same general properties; but in relation to one another, their natures are essentially different, and so completely opposite to each other, that, when combined, they neutralize and balance each other, and all visible action ceases.

c. By friction, or other causes, the union in which these fluids exist in all bodies, is dissolved; the vitreous electricity is impelled in one direction, and the resinous electricity in the opposite one.

Thus, when a piece of glass is rubbed, the vitreous electricity accumulates on the surface of the glass, and the resinous electricity passes over to the rubber.

d. The particles of one fluid have a strong attraction for those of the other; but the particles of the same fluid repel each other (on account of their perfect elasticity), with a force which is in the inverse ratio of the square of the distances.

Hence the attraction which is manifest between two insulated bodies, charged with different electricities, and the repulsion between two insulated bodies, under the influence of the same electricity.

II. Dr. Franklin ascribes all electric phenomena to the agency of a single highly-elastic fluid, which is dispersed through the pores of all bodies, and, from some cause or other, moves through them with various degrees of velocity, according as these bodies are conductors or non-conductors of electricity.

The electric phenomena are then explained thus:—

a. When the attraction which every body has for the electric fluid is equal to the degree of force with which the particles of this fluid repel each other, then no electric phenomena will take place, and the electric fluid is said to be in equilibrium.

b. When a body is *excited*, the electric equilibrium is destroyed; one part of the excited body contains more, and

the other part less, than its ordinary share of electricity. That part which contains more than its natural share of electricity, is said to be *positively* electrified; the other, which has less than the ordinary share, is said to be *negatively* electrified.

c. An insulated conductor of electricity, brought in contact with a positively-excited surface, receives from it part of its surplus of electricity, and becomes, therefore, itself positively electrified. If, on the contrary, the same conductor is made to touch a negatively-excited surface, it will *lose* part of its own electricity, and thereby become *negatively* electric.

d. When a positively-electrified conductor, and another which is negatively electrified, are brought near each other, the surplus of electricity of the one rushes violently over to the negative conductor, and restores the electric equilibrium. This is generally accompanied by a flash of light (a spark), and the other phenomena described in § 313, 314, pages 238 and 239.

REMARK. Dr. Franklin's theory explains all electric phenomena full as well as Du Fay's. The only apparent difficulty seems to be in the repulsion of two-negatively-electrified bodies; for which purpose we must assume that the particles of a body which are void of electricity repel each other, in the same manner as those which are actually charged with the fluid. It is on this account, and because, according to Dr. Franklin, the electric fluid must have the same attraction for *all* bodies, that some modern philosophers (such as Biot, Berzelius, Meissner, Strommeyer, Tobias Mayer, &c.) still adhere to Du Fay's theory, although Dr. Franklin's theory, on account of its simplicity and elegance, is, and justly deserves to be, preferred by most electricians.

ELECTRICAL INSTRUMENTS.

§ 330. Besides the electrical machine, there are yet a variety of other instruments for the purpose of exhibiting the electric phenomena. Among these we will merely mention the following three:—the *electric jar*, or *Leyden phial*, the *electrical battery*, the *electraphorus*, and the *condenser*.

§ 331. The *Electric Jar*, or *Leyden Phial** (Fig. 171), for the purpose of accumulating large quantities of electricity.

Fig. 171.

It consists of a jar or bottle, provided on both sides with a coating of tin-foil; leaving, however, a sufficient space uncovered at its upper part, to prevent a spontaneous discharge (which might occur, if the two coatings were not entirely separated from each other). A metallic rod, rising two or three inches above the jar, and ending in a brass ball, A, called the *knob* of the jar, extends through the cover, and is in contact with the interior coating. The outer coating communicates with the ground.

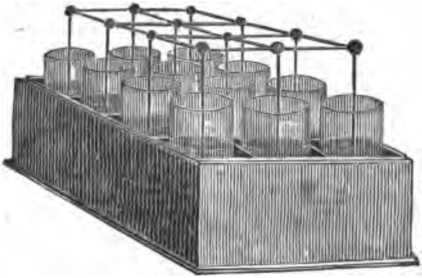
§ 332. When the knob is brought in contact, or communicates with the prime conductor of an electrical machine, then the positive electricity, which is accumulated at the surface of the conductor, passes through the knob to the interior coating, whence its escape is prevented by the interval of uncovered glass (a non-conductor), while the outer coating becomes, at the same time, negatively electrified. In this state the phial is said to be *charged.*

The phial may also be charged by connecting the knob with the negative conductor of the machine (the conductor of the electricity of the rubber); but then the inner coating will be negatively, and the outer coating, positively, electrified. If the knob, instead of *touching* the conductor of the machine, is brought within its *striking distance*, then a succession of sparks will pass from the conductor to the knob; and if the phial is insulated, and the knuckle, or any round conductor, be presented to the outer coating, the same number of sparks will be drawn from it, simultaneously with those of the conductor. An insulated phial cannot be charged.

§ 333. *Electric Battery.* When several electric jars or phials are connected together, a prodigious quantity of electricity may be accumulated. They then receive the name of an *electric battery*. (See Fig. 172.) For this purpose, the inner coatings must communicate with each other by metal-

* So called, because Cunæus and Muschenbroek, in Leyden, first constructed these phials, in 1745. The discovery was made accidentally, by Von Kleist, the 11th of October, 1745.

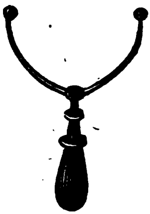
Fig. 172.



lic rods, and the outer coatings must have a similar communication with each other, which is commonly established by placing the phials with their covered bottoms on a sheet of tinfoil. When this is done, the whole battery may be charged like a single phial.

§ 334. *Jointed Discharger.* For the purpose of *discharging an electric jar or battery,* which is done by establishing a direct communication between the inner and outer coating (between the positive and negative electricity), we make use of an instrument called the *discharging rod,* or *jointed discharger.* It consists of two bent metallic rods (Fig. 173), terminating in two brass balls, and fixed in such a manner to a glass handle, that they may be closed or separated like a pair of compasses. When one ball touches the exterior coating, and the other is quickly turned towards the knob of the phial or battery, then a discharge is effected, accompanied by a much greater spark and shock than can be obtained from the conductor of an electrical machine. The glass handle (which is a non-conductor) secures the person who holds the discharger from the effect of the shock.

Fig. 173.

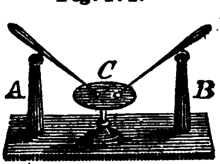


§ 335. *Electric Circuit.* To convey a whole charge of electricity through any substance or person, we must form an *electric circuit,* that is, we must place that substance or person between two conductors, of which one communicates with the inner, and the other with the outer coating of the phial.

A number of persons may receive the electric shock at the same time, by taking hold of each other's hands, the last on one side communicating with the inner, and the last on the other side with the outer coating.

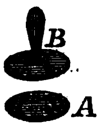
§ 336. *Universal Discharger.* An excellent instrument for directing a charge of electricity with certainty and precision, is *Henley's universal discharger.* It consists of two movable wires or metallic rods (Fig. 174), terminating in little brass balls, and insulated by two glass columns, A and B. When one of the wires is brought in contact with the outer coating, while the other is made to touch the knob of the phial, then a direct charge is sent through the body, which is placed upon a little insulating table, C, between the extremities of the two wires. With this instrument a charge may be directed through any part of a body with the greatest accuracy.

Fig. 174.



§ 337. The *Electrophorus* (invented by Volta, in 1775*) is an apparatus for collecting weak electricities. It consists principally of three parts, the *electric*, the *sole*, and the *cover*. The electric is a cake of some resinous substance, such as sulphur, sealing-wax, pitch, &c. This is melted upon the sole, A (Fig. 175), which is a conducting plate, provided with a rim to contain the cake. The cover, B, is a round, metallic plate, with an insulating handle.† All parts of the electrophorus must be smooth and well rounded, to prevent the escape of electricity.

Fig. 175.



§ 338. *Effects and Management of the Electrophorus.* The cake of the electrophorus is first excited, by rubbing it with woollen cloth or fur; its electricity (according to

* Wilcke made use of a similar instrument previous to Volta. (See Memoirs of the Swedish Academy, Vol. XXIII.)

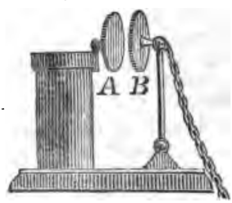
† Instead of an insulating glass handle, the cover may be raised and placed upon the cake by three silk cords, which answer the purpose equally well.

what has been said, § 324) will be resinous, or negative. Then the cover, held by its insulating handle, is placed upon it; in which state the cover does not actually touch the cake, but is yet sufficiently near it to acquire, at its lower surface, the opposite (that is, the positive), and at its upper surface the same (that is, the negative) electricity. When, in this situation, the upper negative surface of the cover is touched with the knuckle, or any metallic conductor that communicates with the earth, a spark will pass from this conductor to the cover, to establish the electric equilibrium. If the cover is now removed by its insulating handle, it is found to be positively charged, and its electricity may be imparted to an insulated conductor, or a Leyden phial. This operation may be repeated a great number of times; the negative electricity of the cake continuing sometimes undiminished for several months.

If the cover is raised without previously receiving a spark from some conducting substance, then it will exhibit no sign of electricity; for in this case it will actually have received none, its electric state having been caused only by the vicinity of an electrified substance. If the sole be insulated, a spark may be drawn from it when the cake is excited; and if, when the cover is on the cake, the cover be touched with one finger, and the sole with another, a shock will be felt, similar in effect, though of course weaker, than that obtained from a Leyden phial.

§ 339. The *Condenser* is another instrument for collecting weak electricity from a large surface into a small body. This was likewise invented by Volta (1775). It consists of a small plate, A (Fig. 176), which is connected with the substance whose electricity we wish to examine. This is brought within a very small distance of another metallic plate, B, which communicates with the earth. The small electricity of the substance connected with the plate A, excites by induction the opposite state of electricity in B. The plate B reacts now upon the plate A, and increases its capacity for receiving electricity from the substance connected with it.

Fig. 176.



Thus a new quantity of electricity is accumulated in A, which again reacts upon the plate B; and so does this mutual action and reaction continue, until an electric equilibrium is established. If the plate A is now separated from the electrified substance, and, thus insulated, removed from B, it is found by the electrometer to be charged with positive electricity.

The condenser and electrophorus have received various shapes, and have been modified according to the different tastes of electricians; but the principle on which these instruments are constructed, is the same as that which we have stated.

OF THE MOTION OF ACCUMULATED ELECTRICITY.

§ 340. The electric fluid chooses, on its passage, always the best conductors, although they be more circuitous; but when different passages are opened to it through equally-good conductors, then it always chooses that which is the shortest.

Thus, if a person, holding a wire between his hands, discharges a jar by means of it, the whole of the fluid will pass through the wire, without affecting him; but if a piece of dry wood be substituted for the wire, he will feel a shock; for, the wood being a worse conductor than his own body, the charge will pass through the latter, as being the easiest, although the longest passage. During its passage through the human body, the shock is felt only in those parts which are situated in the direct line of communication; and, if the charge is made through a number of persons who take each other by the hand, each will feel the electric shock in the same manner and at the same instant, the sensation reaching from hand to hand directly across the breast. By varying the points of contact, the shock may be made to pass in different directions; and this may either be confined to a small part of a limb, or be made to traverse the whole length of the body, from head to foot.

§ 341. The velocity with which electricity moves through a conductor, has not yet been ascertained. In an electric circle of four miles in extent, the shock is felt with the same intensity, and in every point simultaneously.

Experiments of this kind have been made in England, France, and Germany; but they are far from being satisfactory, and have

not as yet led to any conclusion as to the manner in which electricity moves, or the velocity with which its particles are propelled.

§ 342. When the electric fluid meets with an impediment to its passage, either in a bad conductor, or the inadequate size of it, then both its velocity and its effect are diminished in proportion to the degree of obstruction. In this case, the electric fluid is often seen to deviate from its circuit, and to fly off to better conductors, which it may find in the vicinity of its passage.

§ 343. When the metallic passage offered to a stream of electricity is interrupted by small pieces of glass, or other non-conducting substances, small sparks are seen to pass through all the interruptions of the conducting substance, resembling, through its whole extent, a continued stream of light.

This peculiarity in the motion of electricity explains a number of experiments; such as the formation of words and figures on a piece of glass on which fragments of tin-foil are pasted, sufficiently near each other for the electric fluid to pass between them; the chain of light, and other electrical toys.

EFFECTS OF ELECTRICITY UPON BODIES.

§ 344. *Simple Accumulation.* The simple accumulation of electricity in bodies does not produce the least sensible change in their properties.

A person standing on an insulating stool (with glass legs), may be charged with any quantity of electricity from a machine without being in any wise affected by it, until the electric equilibrium is destroyed by drawing a spark from him. Moreover, the electric fluid is accumulated only on the surface, and leaves the rest of the body in a state of perfect neutrality.

§ 345. *Charge sent through a Non-Conductor.* The uninterrupted passage of electricity through a conductor of sufficient size, does not produce the least perceptible change in the mechanical properties. But when a charge of electricity is sent through a non-conductor, or through a conductor of insufficient magnitude, then the body is often burst or rent by the immense rapidity with which the electric fluid passes through it.

§ 346. The *mechanical* effects of electricity on non-conductors which are in the line of its course, are similar to those produced by a sharp instrument driven with great violence and velocity through the substance of a body. Many of the effects of electricity, however, seem to be the result of expansion, produced by the heat, which, more or less, accompanies all electrical phenomena.

OF THE ELECTRICITY OF THE ATMOSPHERE.

§ 347. *Electricity of the Air.* Our atmosphere is almost continually charged with electricity, varying in quantity and intensity, and frequently changing from the positive to the negative state. It is stronger in the day-time than during the night, increasing from sunrise till about 9 o'clock, and is weakest from 12 till 4 o'clock in the afternoon.

§ 348. The electricity of the air is generally positive, particularly in clear weather. On the approach of fog, rain, snow, or hail, it changes often from positive to negative; but afterwards undergoes new transitions to opposite states. On the approach of a thunder-storm, these alternate states of electricity follow each other with surprising rapidity.

Method of ascertaining the Electricity of the Atmosphere. To discover the electricity with which the air is charged, a metallic rod may be employed, raised to some eminence above the ground. When its lower end is insulated, it will show its electrical state by affecting an electrometer, with which it must be connected. To investigate the electricity of higher strata of air, a kite may be used, having in its string a slender piece of wire interwoven.

§ 349. *Analogy of the Electricity of a Leyden Phial with that of a Thunder-cloud.* The analogy between the discharge of a Leyden phial and the electricity of a thunder-cloud was already observed by several philosophers, particularly the Abbé Nollet; but it was reserved for the immortal Franklin to prove, *by actual experiment*, the identity of the electric fluid with that of lightning.

On an approaching storm, in June, 1752, he raised a kite, attached a key to the lower end of the hempen string, and in-

sulated the whole by a silk cord. After waiting for some time, Dr. Franklin observed the bristling up of some of the fibres of the hempen string, and on presenting the knuckle to the key, he obtained a spark.* Dr. Franklin's discovery is by far the most important and practical application of the whole science of electricity. It led him to the invention of the lightning-rod for the protection of buildings and vessels from one of the most dreaded agents in nature, and explained at once the most interesting phenomenon of meteorology.

§ 350. *Method of securing Buildings from the Effects of Lightning.* To secure buildings from the effects of lightning, pointed metallic rods should be placed at least two or three feet above the highest part they are to protect. Their thickness must not be less than half an inch, and they ought to be continued, *without interruption*, into the ground below the foundation of the house, until it reaches either water or a moist stratum of earth.

For the construction of lightning-rods, copper is preferable to iron; copper being a better conductor of electricity, and less liable to rust. The points of the lightning-rod ought to be gilt, or be made of platina, to secure them from corrosion. Large buildings require several rods; for it has been found by experiments, that each rod protects only a circle whose radius is twice the height of the rod above the building.

RECAPITULATION.

OF ELECTRICITY.

Phenomena.

[§ 313.] What takes place when a piece of sealing-wax, or a smooth surface of glass, is briskly rubbed with a dry woollen cloth, and immediately afterwards held towards light and small bodies, such as paper, thread, cork, &c.? What do you call this property which some bodies acquire by be-

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* The same experiment was made by Dallibard and De Lors, but only *in consequence of Dr. Franklin's suggestion.*

ing rubbed? What do you call the surface, which thereby acquires an attractive and repulsive power? What do you call the bodies themselves which produce these phenomena? What, the agent to which they are ascribed?

What are the principal electrics? Why is the division of bodies into electrics and non-electrics no longer practicable?

[§ 314.] What takes place if the experiments which you have just described are performed in a darkened room? What, if the knuckle or a round metallic ball is presented to the surface? What kind of feeling is excited in the skin, if the face is brought near it?

[§ 315.] What takes place when a metallic tube, perfectly round on all sides, and either suspended by silk cords, or supported by a piece of glass or sealing-wax, is brought near or in contact with an excited surface? What is the body, in the first case, said to be? What, in the second case? Do glass, silk, and sealing-wax, brought in the same manner near or in contact with the excited surface, exhibit the same influence?

[§ 316.] What are we, from this and similar experiments, led to infer? What are *conductors* of electricity? What, *non-conductors?*

What are the principal conductors of electricity? What are the principal non-conductors?

[§ 317.] When is a body, which is capable of conducting electricity, said to be insulated?

In what does the difference between a conductor and a non-conductor principally consist?

[§ 318.] What relation exists between electrics and non-electrics, conductors and non-conductors of electricity?

[§ 319.] Is the electricity, communicated by transfer to an insulated metallic body, for any considerable time permanent? What becomes of its electricity when it is touched by a conducting body which communicates with the earth?

[§ 320.] What is the proper shape for a body which shall contain electricity for a considerable time? Why is a pointed figure unfit for this purpose?

[§ 321.] What are the principal parts of an electrical machine?

How is the best machine for this purpose constructed?

[§ 322.] When you present the knuckle, or any round conductor, to the conductor of an electrical machine, what do you obtain? What do you call this spark? What is the greatest distance at which a spark may be drawn, called?

What is necessary to produce these phenomena to their fullest extent? Are the sparks near the conductor greater or smaller than farther from it?

Opposite Electricity.

[§ 323.] To whom are we indebted for the discovery of opposite electricity? On what phenomena and experiments is it established?

[§ 324.] *What laws do these experiments establish?*

[§ 325.] What did Du Fay call these two kinds of electricity? By what signs is it customary to denote resinous and vitreous electricity? How may the general law of opposite electricity, then, be expressed?

When the rubber of an electrical machine is also provided with a conductor, what kind of electricity will this conductor exhibit? What will be the electricity of the prime conductor?

[§ 326.] Does the law, which you have just given, hold only of excited electricity, or does it also hold true of that electricity which is transferred from an excited surface to another body?

How may this be shown by little pith-balls?

[§ 327.] What are the names of the instruments whose construction is founded upon the repulsive power which one electrified body exercises upon another, which is under the influence of the same electricity?

How is Henley's electrometer constructed? What other advantage is taken of the attractive and repulsive power of opposite electricities?

[§ 328.] What takes place when a piece of metal, shaped in the form of an S, and pointed at both ends, is placed upon a pointed wire, which communicates with either of the conductors of an electrical machine? What is ob-

served when this experiment is performed in the dark? When are the electric phenomena generally accompanied by light?

Theory of Electricity.

[§ 329.] How many different theories are there to account for the various phenomena of electricity? Who are the authors of these theories? What is Du Fay's theory? What properties do the two electric fluids, which, according to Du Fay's theory, pervade the earth and all bodies, possess?

How does Du Fay's theory explain the vitreous electricity, excited by rubbing a piece of glass? How, the attraction which is manifest between two insulated bodies, charged with different electricities? How, the repulsion between two insulated bodies, under the influence of the same kind of electricity?

To what agency did Dr. Franklin ascribe all electric phenomena? How are the electric phenomena, then, explained?

Electrical Instruments.

[§ 330.] Are there any other electrical instruments, besides the electrical machine, deserving of our notice? What are they?

[§ 331.] What does an electric jar or Leyden phial consist of? What do you call the knob of the phial?

[§ 332.] What takes place when the knob is brought in contact, or communicates with the prime conductor of an electrical machine? What is the phial in this state said to be?

Can the phial be charged by connecting the knob with the negative conductor of the machine; that is, with the conductor of the electricity of the rubber? What kind of electricity will thus be imparted to the inner coating? What do you obtain, if the knob, instead of touching the conductor of the machine, is brought within its striking distance? What, if the phial is insulated, and the knuckle, or any round conductor, is presented to the outer coating? Can an insulated phial be charged?

[§ 333.] By what means can prodigious quantities of electricity be accumulated? When several electric jars or phials are connected together, what name do they receive? What is necessary to establish, for this purpose, between the inner and outer coatings? When a communication is established between the inner and outer coatings, how is the whole battery then charged?

[§ 334.] How is an electric jar or battery discharged? What instrument is used for this purpose? What does this instrument (the discharging rod) consist of? How is a discharge of a phial or battery effected by it? What is this discharge accompanied by? What is the use of the glass handle, with which every discharging rod is provided?

[§ 335.] What is necessary in order to convey a whole charge of electricity through any substance or person?

By what means can a number of persons receive the electric shock at the same time?

[§ 336.] By what instrument can a charge of electricity be directed with the greatest certainty and precision? What does Henley's *universal discharger* consist of? How is a direct charge sent through a body by means of this instrument?

[§ 337.] What is the name of an apparatus for collecting weak electricities? By whom was it invented? What are its principal parts? What is the electric? How is the electric combined with the sole? What does the cover of the electrophorus consist of? How must all parts of the electrophorus be shaped, in order to prevent the escape of electricity?

[§ 338.] By what is the cake of the electrophorus first excited? What kind of electricity will it by these means receive? What kind of electricity do the upper and lower surface of the cover acquire, when placed upon the excited cake? What takes place, when, in this state, the upper (negative) surface is touched by the knuckle, or any metallic conductor, that communicates with the earth? If the cover is now removed by its insulating handle, with what kind of electricity is it found to be charged? What can be done with this electricity? How many times may this operation be repeated?

How long does the electricity of the cake continue? Does the cover exhibit any sign of electricity when it is raised without previously receiving a spark from some conducting substance? Why not? In what case can a spark be drawn from the sole? What is felt, if, while the cover is on the cake, the sole is touched with one finger, and the cover with another?

[§ 339.] What kind of instrument is a *condenser?* By whom was it invented? Of what does it consist? What is the mutual operation of the plates, when one of them is connected with an excited substance? How long does the mutual action and reaction of the two plates of the condenser continue? If the plate which is connected with the electrified substance is now separated from it, and, thus insulated, removed also from the other plate, with what is it found to be charged?

Motion of Accumulated Electricity.

[§ 340.] What kind of bodies does the electric fluid always choose on its passage? What passage does it choose when several passages are opened to it through equally good conductors?

Is a person, holding a piece of wire in his hands, affected by the discharge of a Leyden phial? What will he feel if a piece of dry wood is substituted for the wire? When accumulated electric fluid passes through the human body, is the shock felt in the whole body, or only in certain parts? In what line are the parts affected by the shock situated? If a charge of electricity is sent through a number of persons, who take each other by the hand, how and where will each of them feel the shock? By what means can the shock be made to pass in different directions?

[§ 341.] Has the velocity with which electricity moves through a conductor, been, as yet, ascertained? How is the electric shock felt in a circuit of four miles?

[§ 342.] How is the velocity of the electric fluid affected, when it meets with an impediment to its passage, either in a bad conductor, or in the inadequate size of it? What is the eleotric fluid, in this case, frequently observed to do?

[§ 343.] What is observed when the metallic passage, offered to a stream of electricity, is interrupted by small pieces of glass or other non-conducting substances?

What phenomena does this peculiarity in the motion of accumulated electricity explain?

Effect of Electricity on Bodies.

[§ 344.] Does the simple accumulation of electricity in bodies produce the least perceptible change in their properties?

Is a person, standing on an insulating stool, and, in this state, charged with any quantity of electricity from a machine, in any manner affected by it, before a spark is drawn from him? Does the electric fluid spread through the whole substance of a body, or does it merely accumulate upon its surface?

[§ 345.] Does the uninterrupted passage of electricity through a conductor of sufficient size, produce any perceptible change in its properties? But what takes place when a charge of electricity is sent through a non-conductor, or through a conductor of insufficient magnitude?

[§ 346.] What are the mechanical effects of electricity on non-conductors, which are in the line of its course, similar to? To what other agent are many of the effects of electricity attributed?

Of the Electricity of the Atmosphere.

[§ 347.] With what is our atmosphere almost continually charged? Is the quantity in which electricity exists in the atmosphere, always the same? Is it always of the same (positive or negative) kind? Is it stronger in day-time, or during the night? During what hours of the day is it strongest? When is it weakest?

[§ 348.] With what kind of electricity is the air generally charged in clear weather? When does it change from the positive to the negative state? On what occasions do these alternate states of electricity follow each other with surprising rapidity?

By what means may the electricity with which the air is charged, be discovered? By what means may the electricity of higher strata of air be investigated?

[§ 349.] Who first proved, by actual experiment, the identity of the electric fluid with that of lightning?

(The teacher might here ask for the occasion which led Dr. Franklin to this discovery.)

[§ 350.] In what manner may buildings be secured from the effect of lightning? What ought to be the thickness of the rods, which are to be placed upon the highest parts of the buildings they are to protect? How far ought they to be continued?

What metal is preferable to iron for the construction of lightning-rods? Why? Why ought the points of the lightning-rods to be gilt, or be made of platina? Why do large buildings require several rods to protect them against the effects of lightning?

CHAPTER X.

OF GALVANISM.

§ 351. *Electricity produced by Contact, Heat, &c.* Although friction is the principal means of exciting electricity, yet we know from experience, that there are other causes equally productive of electric phenomena, though more feeble in degree than those we have treated of in the last chapter. Among these we reckon *heat*, *chemical affinity*, and the heat which is produced *by contact*.

Different degrees of heat affect the conducting power of water; and it has been said before, that ice at — 13° Fahrenheit is an electric; consequently, a non-conductor of electricity. Late experiments have proved that changes of temperature produce similar effects in other substances. Glass, when red hot, is no longer an electric, but becomes a conductor of electricity. But the most striking instance of this kind is exhibited by the *tourmaline*. This is a stone hard enough to scratch glass, of various colors and forms, transparent when viewed across its thickness, and perfectly opaque in the opposite direction. It becomes electric by heat, and, when in this state, affects iron-foil, and other metals, in a manner similar to that of the loadstone. (See Chap. XI. On Magnetism.) The electric phenomena produced by chemical agency, belong to a different branch of the natural sciences.

§ 352. *Explanation of the term Galvanism.* The electric phenomena produced by contact are so numerous and complicated, and have given rise to so many theories and conjectures, that it has become necessary to treat of them as a distinct science, which, from its author, Aloysius Galvani,* is termed *Galvanism*.

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* Dr. Aloysius Galvani, Professor of Anatomy in Bologna (born 1737, died Dec. 5, 1798), was led accidentally to this discovery in 1790. One of his pupils happened to touch the bare nerve of a frog, that had been recently skinned, with the blade of a knife, while another was turning an electrical machine in its immediate neighborhood.

§ 353. *Facts on which the Theory of Galvanism depends.* The two principal facts on which the whole theory of galvanism is established, are these :—

1. The contact of two metals produces in the one an accumulation of positive electricity, or + E, and in the other negative electricity, or — E.

2. All living bodies are, through the medium of the nerves, more or less affected, when brought in contact with two heterogeneous metals.

§ 354. *Effects produced on the Human Body.* Among the effects produced on the human body by galvanism, it will suffice to mention the following three :—

1. When any wounded place is touched by two different metals, a very acute pain is felt as soon as these metals are brought in contact with each other.

2. If a piece of silver is placed upon the wet end of the tongue, and a piece of zinc is placed under the tongue, and the zinc is brought in contact with the silver, an acid taste is felt; and when the order in which the metals are placed is reversed, the taste becomes of a more burning and pungent nature.

3. When one of the metals is placed against the moist corner of the eye, while the other touches the gum of the lower jaw, then, the moment the two metals are joined, a sensation of light is felt in the eye, as if proceeding from distant lightning.

The convulsion into which the leg of the frog was suddenly thrown, and other similar experiments, afterwards made by Galvani, and repeated by others, led him to the idea that every muscle of the animal body resembled in its operation an electric battery; that the different fibres of which it consists are so many electric jars, which are continually charged with electricity from the brain, through the conducting powers of the nerves, &c. But this theory was soon afterwards exploded by Professor Volta, of Pavia, who proved by experiment, that the same convulsions in the legs of frogs and other animals, may be occasioned by touching *the nerve alone* with two different metals, as soon as *these metals themselves* are brought in contact with each other. Modern philosophers have gone further, and produced the same phenomena with *homogeneous* metals, by giving each a different form or polish, or varying their temperature. Baron von Humboldt produced sudden convulsions in the leg of a frog, with two pieces of metal of the same kind, by the mere breath of his mouth. See his interesting work "Über die gereizte Muskel und Nervenfaser." Berlin and Posen, 1797.

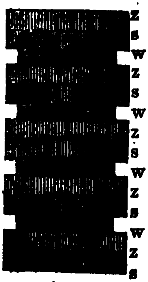
This sensation of lightning is purely *physiological;* as it is only felt by the individual who is performing the experiment, and not by those who are near him. The phenomena just described explain, in some measure, why certain liquids, such as beer, ale, wine, &c., taste differently when drank out of metallic vessels, from what they do when drank out of glasses; why food prepared and served up in metallic vessels or plates, tastes not so pure as when prepared in earthen vessels, and served up on china, &c.

§ 355. The influence of galvanic electricity on the bare nerves and muscles of dead animals, is manifest by the sudden convulsions into which they are thrown, when touched by different metals, which are themselves brought in contact with each other. Cold-blooded animals, particularly those which are amphibious, are more affected by galvanic electricity than quadrupeds or birds.

Galvani's experiment with the bare leg of a frog (see the note to page 261), can easily be repeated, by forming a chain of conducting substances between the outside of the muscles and the crural nerve; or by placing a piece of zinc under the nerve of the leg, and a piece of silver (for which purpose a small coin may be used) upon the muscle. The moment the zinc and the silver are connected by a conductor, say a piece of bent wire, the whole of the leg is thrown into violent convulsions; but if the connecting substance be a non-conductor, for instance, a piece of bent glass, no such phenomenon will take place.

§ 356. *Voltaic Pile.* The electricity produced by contact can be much increased, and its effects be rendered more visible, by an apparatus which, from its illustrious inventor (Professor Volta), is called the *Voltaic pile.* It consists of a number of silver coins (of the size of a dollar), and an equal number of pieces of zinc, of the same form and dimensions. Between each pair of these metals is placed a piece of wet card or cloth (a conductor), of somewhat less dimensions than the metallic plates. Great care must be taken to preserve throughout the same order, viz. silver, zinc, wet cloth—silver, zinc, wet cloth, &c.; so that the two extremities of the column may contain different metals; one end silver and the other zinc, as may be seen from Fig. 177. (S, Z,

Fig. 177.

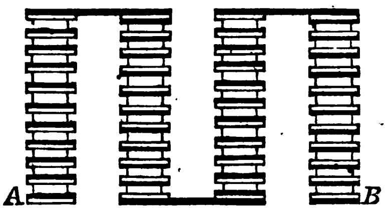


respectively, stand for silver and zinc, and W for wet cloth or card.) These ends are called the *poles* of the pile; one is called the silver pole, and the other the zinc pole.

Instead of silver, copper may be used, by which means the pile becomes less expensive. If the pile is to produce the desired effect, there ought not to be less than 50 pairs of plates, and the cloth or card ought to be wet with a solution of salt, which greatly increases its conducting power.

§ 357. *Voltaic Battery.* Several voltaic piles may be connected with each other, so as to form a *voltaic battery.* This is done by establishing a direct metallic communication between the last plate of the one and the first of the next pile; this is connected in the same manner with the third pile, and so on, observing always the same order of succession in the plates, as represented in the figure. (The dark lines represent the silver or copper plates, and the light lines the zinc plates.) The two extremities, A and B, of the battery, are again called the silver and zinc pole of the battery.

Fig. 178.



§ 358. *Experiments made with the Voltaic Pile.* The most remarkable experiments that can be made with the voltaic pile or battery, are the following:—

1. If each end of the pile is provided with a piece of wire, and both are seized, one with the right, and the other with the left hand, an involuntary trembling motion is felt, *which continues as long as both wires are held.*

The effect of the voltaic pile upon the nerves may be much increased by wetting both hands, or by conducting each wire into a separate basin of water, and putting the hands into the basins.

2. When the silver or copper pole communicates with the earth, and the zinc pole is connected with a good electrometer (§ 327), it shows *positive* electricity, or + E; but

when the zinc pole communicates with the earth, and the copper pole is connected with the electrometer, then this will show *negative* electricity, or — E. For this reason is the zinc pole called the *positive* pole, and the copper or silver pole is called the *negative* pole of the pile.

3. A small electric jar (§ 331) may be charged with positive or negative electricity, according as the zinc or copper pole is connected with the knob, while the other communicates with the earth.

4. A condenser (§ 339) may be charged with either electricity.

5. When the wire of the zinc pole is brought in contact with the wire of the copper pole, an electric spark is obtained, of sufficient intensity to ignite phosphorus or sulphur, or to consume a small piece of gold-leaf.

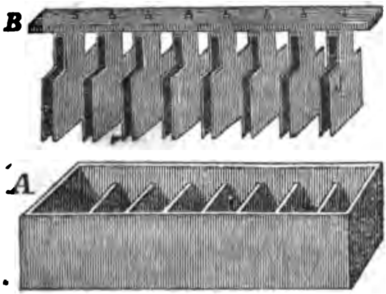
6. When both wires (which, for this purpose, must be of platina or fine gold) are conducted into a glass tube, which is filled with distilled water, the water becomes decomposed into its chemical compounds: the silver or copper pole disengages *hydrogen*, and the zinc pole, *oxygen*.

In general, it may be remarked, that the chemical operations of the voltaic pile are greater and more intense than its mechanical operation; wherefore the whole subject of galvanic electricity forms one of the most important parts of chemistry.

§ 359. *Modern Discoveries*. Among the modern discoveries on the subject of galvanic electricity, the most remarkable is, that the effects of the voltaic pile on the animal body depend chiefly on the *number* of plates that are employed; but the intensity of the spark, and its chemical agencies, increase more with the *size* of the plates, than with their number.

Trough Battery. Instead of separating each pair of plates of the voltaic pile, by a piece of wet card or cloth, a liquid (commonly a saline solution) may be employed for that purpose. Such an apparatus receives, then, the name of a *trough battery*. There are various forms and ways of constructing it. One is represented in the following figure. A represents a trough, made of hard wood, or wedge-wood, with partitions of glass, which divide it into several cells. The plates, B, are fitted to these cells, and are connected together by a slip of wood, so as to admit of being let down and lifted up together. An apparatus of this

Fig. 179.

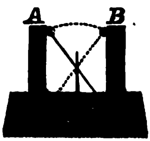


kind is, in its chemical operations, far more powerful than a simple galvanic pile; but its uses and applications cannot be described in an elementary treatise on natural philosophy.*

Attempts have been made to construct voltaic piles without the assistance of liquids, by means of layers of gold and silver paper.† The effect of such piles remains undiminished for several years; but their chemical operation continues weak.

Advantage has been taken of these piles to construct a sort of *electric perpetuum mobile.* It consists of two piles (see the figure), whose poles are inverted, so that if the positive pole of the first pile is at the top, it is, in the other pile, at the bottom; and in a similar manner are the negative poles disposed of. Between the two piles is a pendulum, suspended nearly in its centre of gravity, and provided on both ends with little pith-balls. When the pendulum is set in motion, both balls are at first attracted by the two positive poles, A and D (which situation is represented in the figure). But as soon as both balls have the same (positive) electricity, they are repulsed, and attracted by the negative poles of the piles: from these they are again repulsed, and attracted by the positive poles; and so on.

Fig. 180.



(Such an electric pendulum is in the Polytechnic School of Vienna; and it has been known to continue its operation without interruption for several years.‡)

* Its most remarkable phenomena are described in Berzelius's Chemistry, Vol. I. page 106.

† By Zomboni, Prof. Bohnenberger, and De Luc.

‡ See Prof. Neuman's Treatise on Natural Philosophy, Vol. I. § 878—881. (Neuman's Lehrbuch der Physik. Wien bey Gerold.)

THEORY OF GALVANIC ELECTRICITY, AND THE VOLTAIC PILE.

(It is to be observed, that the phenomena of the voltaic pile, and the trough battery, are as yet far from being satisfactorily explained. The opinions of the best chemists and philosophers of our time, are, in this respect, at variance with each other. There are, consequently, but few general facts acceded to by all parties; and only these can form part of an elementary treatise.)

§ 360. *Theory of the Voltaic Pile.* There are evidently two kinds of conductors of electricity:—

1. *Exciters;* which, although they oppose no obstacles to the passage of electricity, disturb the electric equilibrium, *when brought in contact with one another*, so that, in this case, one becomes always charged with + E, while the other receives the opposite electricity, or — E.

2. *Mere conductors;* such as afford a passage to electricity, without disturbing its equilibrium.

Metals are the principal exciters of electricity. The following table shows their galvanic relation to each other. Each metal, namely, when combined with one which precedes it in the series, receives + E; but when combined with one that comes after it, then it receives — E.

SILVER.	TIN.
COPPER.	LEAD.
IRON.	ZINC.

Prof. Erman, of Berlin, has lately discovered a third kind of conductors, which he has called *uni-polar* conductors. They conduct only one kind of electricity, and insulate the other. Dry soap, for instance, conducts + E, and insulates — E. The flame of phosphorus conducts — E, but insulates + E. With such conductors, no galvanic pile can be discharged; but they are capable of conducting the electricity of *one* pole to any body capable of receiving it.*

§ 361. The different properties of exciters and mere conductors of electricity, stated in the preceding section, will enable us to explain the operation of the voltaic pile in the following manner:—

* Berzelius's Chemistry, Vol. I. p. 124.

1. When there is but one pair of non-insulated metals, say zinc and copper (the copper below, and the zinc above), then the zinc will receive $+$ E, and the copper — E, from the contact.

2. If a *mere conductor* (such as wet card or cloth) be now placed upon the zinc plate, and a new pair of plates upon this conductor, then the wet conductor will afford a passage to the $+$ E contained in the zinc plate of the first pair. Hence the second zinc plate, which, in contact with copper, must receive a surplus of $+$ E, will contain a greater quantity of positive electricity than the first zinc plate; while the second copper plate, in consequence of an accession of $+$ E from the wet conductor, will have less negative electricity than the first copper plate. In the same manner the pile may be continued; and it is easy to show, that each following zinc plate must contain a greater quantity of positive electricity than its immediately preceding one, whereas the negative electricity diminishes from the bottom, *upwards*, so that the lowest copper plate contains the most — E, and the highest zinc plate the greatest quantity of $+$ E. It is for this reason the two extremities of the piles are called its *poles*.

3. If the lowest copper plate communicates with the floor (as we have supposed in our explanation), then the electricity of the pile will continue by a continued accession of electricity from the earth. If, on the contrary, the pile is insulated, then the quantity of electricity does not increase, but the greatest positive electricity will be condensed at the top, and the greatest negative electricity is at the bottom.

4. When both poles of the pile communicate with the earth, then a continued motion of electricity must ensue, from the bottom of the pile upwards to the zinc pole, whence it is again conducted to the earth.

5. *Galvanic Circle.* If the two poles of the pile communicate with each other by some conducting substance, for instance, a piece of wire, then a *galvanic circle* is formed; that is, the positive electricity passes from the bottom of the pile to the zinc pole, and thence, by means of the conducting substance, again to the bottom of the pile, then again to the zinc pole, and so on.

Those who believe in the existence of two distinct electric

fluids, are of opinion that two separate electric streams produce the phenomena of the voltaic pile; that these streams take opposite directions, the positive fluid moving upwards through the zinc pole, and the negative fluid downwards through the copper pole, both streams meeting each other in the circle. Whichever of the two theories is the correct one, it is certain that the phenomena of the voltaic pile cannot be satisfactorily accounted for, by the mere laws of electricity. A great deal seems to depend upon the conducting liquid, which, by the agency of the pile, becomes decomposed. It is also worthy of notice, that the plates, of which the pile is composed, become themselves oxidated, and that the effects of the pile become more energetic in proportion as the process of oxidation is going on more rapidly.

The farther extension of this theory belongs to chemistry.

ORGANIC-ELECTRIC PHENOMENA.

§ 362. A peculiar electric effect is produced by a certain kind of fish, when they are touched at two different places of their bodies. The shocks thus felt are similar to those obtained from a Leyden phial, or an electric battery. (§ 331, and 333.) They do not, however, affect an electrometer; neither has it as yet been possible to elicit sparks from them.

To this kind of fish belong

The Gymnotus Electricus, or Electric Eel.
The Raja Torpedo.
The Silurus Electricus.
The Trichiurus Indicus.

§ 363. When these fishes are placed upon metallic dishes, or touched on two sides of their bodies by pieces of metal, they lose the power of producing shocks, because the discharge of electricity follows the best conductor, namely, the metal.*

* See Berzelius's Chemistry, Vol. I. page 132.

RECAPITULATION.

Of Galvanism.

[§ 351.] Are there, besides friction, any other means of producing electricity? What are they?

Do different degrees of temperature affect the conducting power of water? At what degree of temperature does ice cease to be a conductor, and become an electric? Are there any other substances upon which changes of temperature produce similar effects? Give instances of this kind. What kind of stone is the *tourmaline?* What property does this stone acquire by heat?

[§ 352.] What is that science called which treats of the electric phenomena produced by contact? Who was the author of galvanism?

[§ 353.] What are the two principal facts on which the whole theory of galvanism is established?

[§ 354.] What are the effects produced by galvanism on the human body?

Is the sensation of light, produced by the contact of different metals, felt also by other individuals, or merely by him who performs the experiment? What phenomena are explained by the effects of galvanic electricity on the body?

[§ 355.] How does the influence of galvanic electricity, on the bare nerves and muscles of dead animals, become manifest? Are cold-blooded animals, or quadrupeds and birds, most affected by galvanic electricity?

Describe Galvani's experiment with the bare leg of a frog. What takes place, when, in this experiment, the zinc and silver are connected by a conductor, say a piece of wire? Is the same phenomenon produced when a piece of glass is substituted for the wire?

[§ 356.] By what apparatus can the electricity produced by contact be much increased, and rendered visible? Who was the inventor of this apparatus? Of what does it consist? What care must be taken in its construction? What are the ends of the voltaic pile called?

What metal may be substituted for silver in the construction of a galvanic pile? If the pile is to produce the desired effect, of

how many plates ought it, at least, to consist? By what means can the conducting power of the cloth or card be increased?

[§ 357.] When several voltaic piles are connected with each other, what are they said to form? By what means is this connection effected? What are the two extremities of the battery called?

[§ 358.] What are the most remarkable experiments that can be made with the voltaic pile or battery?

[§ 359.] What is the most remarkable modern discovery on the subject of galvanic electricity?

If, instead of separating each pair of plates of a voltaic pile by a piece of wet card or cloth, a liquid (a saline solution) is employed, what is the apparatus so constructed called? Describe such an apparatus. Is the chemical operation of the trough battery greater or less than that of a simple galvanic pile? Have any attempts been made to construct voltaic piles without the assistance of liquids? Of what do such piles then consist? How long does the effect of such piles continue? What do you know about their chemical operation? Can you describe the *perpetuum mobile* which is constructed by means of two such piles? How does it operate?

Theory of Galvanic Electricity and the Voltaic Pile.

[§ 360.] How many different kinds of conductors of electricity are there? What are they? What bodies are the principal exciters of electricity? Do you recollect a series of metals, in which each receives + E, when combined with one that precedes it, but — E, when combined with one which comes after it?

What kind of conductors did Prof. Erman, of Berlin, lately discover? Which kind of electricity does dry soap conduct? Which does it insulate? What kind of electricity does the flame of phosphorus conduct? Which does it insulate? Can a galvanic pile be discharged with a uni-polar conductor of electricity? What, then, can such a conductor be used for?

[§ 361.] How do the different properties of exciters and mere conductors of electricity enable you to explain the operation of the voltaic pile? (3.)* Is the electricity of the

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* The questions marked (3), (4), (5), refer to page 68, 3, 4, 5.

pile increased or diminished when the lowest copper plate communicates with the floor? What takes place when the pile is insulated? (4.) What takes place when both poles of the pile communicate with the earth? (5.) What is formed when the two poles of the pile communicate with each other by some conducting substance, for instance, a piece of wire?

How do those philosophers, who believe in the existence of two distinct electric fluids, account for the phenomena of the voltaic pile? How is the conducting liquid affected by the agency of the pile? How are the plates themselves affected? Do the effects of the voltaic pile become weaker, or more energetic, as the process of oxidation is going on more rapidly?

Organic-Electric Phenomena.

[§ 362.] What property is possessed by a certain kind of fish? What are the shocks, which are felt when they are touched at two different parts of their bodies, similar to? Do these fishes affect an electrometer? or has it been possible, as yet, to draw any sparks from them?

Can you tell the names of the fishes which belong to the kind you have just described?

[§ 363.] When do these fishes lose the power of producing shocks? What is the reason of it?

CHAPTER XI.

OF MAGNETISM.

§ 364. Among the black iron ores which contain iron in a feeble degree of oxidation, there are pieces which possess the wonderful power of attracting metallic iron, sometimes in considerable masses. These are called *native magnets*, or *loadstones*. The same power, however, may be communicated to iron and steel by a variety of processes, which we shall become acquainted with hereafter. These are then called *artificial magnets*.

§ 365. Besides iron, there are yet two other metals—nickel and cobalt—which participate the magnetic properties; and, according to the latest discoveries (made by Coulomb), *all solid bodies are susceptible of magnetic influence*, but in so feeble a degree that it is perceptible only by the nicest experiments.*

Native magnets are found in various parts of the world, particularly in the iron mines of Sweden and Norway, in different parts of Arabia, China, Siam, and the Philippine Islands: more seldom, and in smaller masses, in England and Germany.

A.—RELATION OF NATIVE MAGNETS TO UNMAGNETIC IRON.

§ 366. Metallic iron and *black* iron oxide (none other) adhere to native magnets with considerable force.

This power, which may be measured by weight, does not depend on the size, and is variable in one and the same magnet.

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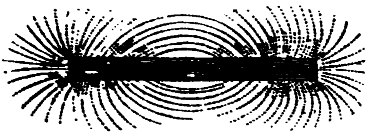
* See Gilbert's Annals of Nat. Philosophy, Vol. IV. page 1; Vol V. p. 384; Vol. XI. p. 367; Vol. XII. p. 194; Vol. LXIV. p. 395.

§ 367. *Poles of the Magnet.* The magnetic power does not operate with equal intensity in all points of the surface. There are in every magnet two places, in which its attractive power is greatest. These are called the *poles* of the magnet.

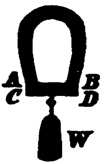
They may be made visible by laying the magnet in iron-filings, which will adhere stronger to the poles than to any other place. (See the figure.) A thin piece of iron will adhere *perpendicularly* to the surface of the poles: in any other place, it will have a position inclined to the poles; and in the middle (the point which is equally distant from both poles), it will remain horizontal, that is, parallel with the magnet.

Fig. 181.



§ 368. When both poles are made to operate at the same time on a piece of iron, the magnetic attraction is increased.

Fig. 182.



Hence it is customary to give artificial magnets the shape represented in the adjoining figure. The two poles of the magnet are then in the same horizontal line, AB. Upon these is placed a piece of malleable iron (commonly called the *armature* of the magnet), which may then be charged with as many weights as the magnet will draw.

§ 369. *Law of Magnetic Attraction.* The attractive power of the magnet manifests itself not only in contact, but also at considerable distances; and it has been proved, that the general law for the attraction of gravity, the propagation of sound, of heat, and light, holds true, also, with regard to the magnet; that is, the magnetic power is in the inverse ratio of the squares of the distances.*

* See Coulomb's Experiments with the Magnetic Balance, in Gren's Journal of Natural Philosophy; Fisher's Mechanical Philosophy; Hauy's Physique; Biot, Essai de Physique, exp. et math. Vol. III.; Gilbert's Annals of Philosophy, Vol. LXIV.

§ 370. When a native magnet is placed under a plate of glass, wood, pasteboard, or even metal, which is thinly covered with iron filings, these filings will form themselves into curve lines, which will appear to emanate from one pole, and to enter into the other.

This experiment proves, that the magnetic influence is not destroyed by the interposition of another substance, with the exception of iron, which, according to its position, either increases or diminishes the operation of the magnet.

§ 371. The power of a magnet is preserved, and even increased, by letting it continually draw as much weight as it is capable of bearing.

Small loadstones may be kept in iron-filings. Oxidation diminishes the attractive power of the magnet. Great heat destroys it.

B.—RELATION OF A MAGNET TO ITSELF, AND TO ANOTHER MAGNET.

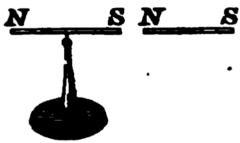
§ 372. *Polarity of Magnets.* When a magnet is so situated that it can move freely in a horizontal position, then it will always place itself in a determined direction, one of its poles pointing to the north, and the other to the south. This wonderful property is called the *polarity of the magnet.*

Upon this property of the magnet is founded the construction of the mariner's compass, which, on account of its utility in navigation, is of universal interest to mankind. Its inventor has not as yet been precisely ascertained, but it is certain that its invention and use can be traced back to the thirteenth or fourteenth century. The ancients knew only the attractive power of the magnet.

§ 373. *Relation of one Magnet to another.* One magnet attracts another magnet stronger than it does iron; but, in certain points, they seem mutually to repel each other; and it is found by experiments, *that the north pole of one magnet attracts the south pole of another, and vice versa; but that the two north poles or the two south poles repel each other.*

This law may be easily exhibited by placing a magnet nearly horizontally upon a pivot, so that it can freely move upon it. In this situation, its south pole will follow the north pole of another magnet, but recede from its south pole. The two poles which thus mutually attract each other, are by some philosophers called the *friendly poles*, while those which seem to repel each other, are called the *inimical poles* of the magnet.

Fig. 183.



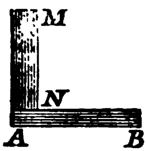
IMPARTING OF MAGNETISM.

§ 374. ***Methods of making Artificial Magnets of Iron or Steel.*** This is done in three ways—by the *single touch*, by the *double touch*, and *by percussion*.

§ 375. Method by *single touch*.

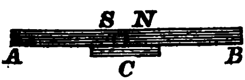
1. For this purpose, a bar of iron is laid flat on a table, and a magnet, at right angles, slid several times along its surface. In this operation, care should be taken to slide the magnet always in the same direction.

Fig. 184.



2. When *two* magnets are employed, the effect is still more powerful. The two magnets are placed, with their dissimilar poles in contact, upon the middle of the bar, C, that is to be magnetized. (See the figure.) They are then drawn in opposite directions (one towards B, and the other towards A). When arrived at the two extremities of the bar, they should be perpendicularly removed to a considerable distance, then again joined with their dissimilar poles, and placed upon the mid-

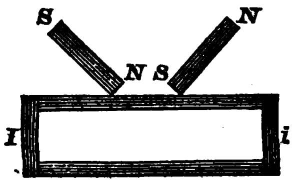
Fig. 185.



dle of the bar. This operation must be repeated several times on both sides of the bar.

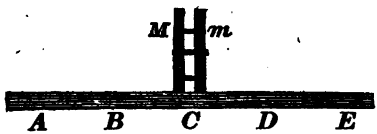
3. A third method of communicating magnetism by the *single touch*, and the most effectual of all, is to place two bars, which are to be magnetized, parallel to each other, and to connect them by two shorter pieces of soft iron, I, *i*, so that the whole forms an oblong. (See the figure.) The north and south poles of the magnets are again brought in contact over the middle of the bar, and inclined so as to make a right angle with each other. The remainder of the operation is then similar to that described in No 2.*

Fig. 186.



§ 376. Method by *double touch*. The bars, A, B, C, D, E, which are to be magnetized, must be of equal size, and are placed in a straight line, in contact with each other. (See the figure.) Two magnets, or parcels of strongly-magnetized bars, M, *m*, with their poles reversed, are fixed, parallel to each other, at a distance of about a quarter of an inch. These are placed perpendicular to the line of bars, and, in this situation, slid backwards and forwards on both sides of the bars, until a sufficient effect is obtained.

Fig. 187.



This method, which was first published by Mitchel, of Cambridge, in 1750, has since been improved by Canton, Æpinus, Biot, Coulomb, and others. The principle is nearly the same in all.

§ 377. Method *by percussion*. In this case, the steel bars are best formed into parallelopipeds, or right-angled

* This process was devised by M. Duhamel, in conjunction with M. Anthcaume, both of the French Academy of Sciences.

prisms. They are then inclined nearly vertically, the lower ends deviating to the north, and, in this position, struck several times with a hammer, by which means they will acquire all the properties of a magnet.

When, in this manner, the steel bars are hammered upon soft iron or steel, their magnetic power is found to be much greater than if they are hammered on wood or any other substance.

§ 378. The general law, which is observed in making artificial magnets, by any method whatever, is this:—*Each extremity of the magnetic bar becomes the opposite pole to that with which it is last touched.* Thus the extremity of the bar which is touched by the south pole of the magnet, becomes the north pole of the artificial magnet; while that extremity which is last touched by the north pole of the magnet, becomes the south pole of the bar.

Soft iron is sooner magnetized than steel; but the magnetic power communicated to steel is more permanent than in iron.

§ 379. The magnet which is employed in magnetizing a steel bar, loses little or nothing of its own power. Thus, with one magnet, a number of bars may be magnetized, and then combined together, by which means their power may be indefinitely increased. Such an apparatus is then called a *magnetic magazine.*

§ 380. *Communication of Magnetism by Induction.* As long as a piece of iron is attached to a magnet, it is itself magnetic, and attracts other iron or steel. In this case, the iron is said to be magnetic only *by induction;* and it is to be observed, that this magnetic power disappears almost entirely as soon as the magnet is removed from the iron.

§ 381. The law of magnetic induction is similar to that of electricity. And it is easy to prove, with a magnetic needle, that the south pole of the magnet excites the north pole, in that end of an iron bar which is in its immediate neighborhood, and the south pole at the other extremity, which is most remote from it; so that each pole of the magnet communicates the opposite state of magnetism to the neighboring iron.

§ 382. This law, being perfectly similar to that of electricity, has led some philosophers to think that magnetism

and electricity originate from the same cause, or are, at least, manifestations of the same power in nature, although Franklin and others seem to have been of a different opinion.*

Æpinus supposed all magnetic phenomena to proceed from a single fluid, whose particles mutually repel each other, but have a strong attraction for iron and steel. This fluid is every where in perfect equilibrium. Iron and black iron oxide are filled with it, but the fluid is throughout equally distributed in them. In magnet, on the contrary, there is a surplus of the fluid on one side, and a deficiency on the other. The surplus of magnetism he calls + M, and the deficiency or want of it he calls — M, &c. The whole theory is analogous to Dr. Franklin's theory of electricity. (See § 329, page 244.)

Wilcke and Brugman believe in the existence of two magnetic fluids, which have great attraction for each other, but the particles of either fluid repel each other. In iron they are combined together, and in this state produce no magnetic phenomena. In magnets, on the contrary, they are separated: one fluid accumulates at the north pole, and the other at the south pole, &c. (Compare this theory with Du Fay's theory of electricity.)

OF THE VARIATION AND DIP OF THE MAGNETIC NEEDLE.

§ 383. When an unmagnetic iron needle is poised in its centre, upon a sharp point, so that its position is perfectly horizontal, and it is afterwards magnetized, then, in most places, it will not exactly point to the north, neither will it remain in its horizontal position; but its acquired south pole will considerably incline to the horizon, forming generally an angle of about 7 degrees. The *deviation* from due north, is by mariners called the *declination* or *variation of the compass;* the inclination to the horizon is called the *dip of the magnetic needle.*

§ 384. *Variation of the Compass.* The north pole of the compass deviates, in England and throughout Europe, from about 16 to 18 degrees westward. These deviations become smaller the farther we go to the west; and through

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* See Franklin's letter in Sigaud de la Fond Précis historique et experimental des Phenomènes électriques. Paris, 1781.

America and the Gulf of Mexico goes a line, in which the compass points exactly north. This line is called the *line of no variation.* Beyond this line the deviation is to the eastward.

The line of deviation seems to form a great circle, beginning westward of Baffin's Bay, crossing the United States, and passing along the Gulf of Mexico, Brazils, and the South Atlantic Ocean, towards the south pole. It reappears in the western hemisphere, south of Van Diemen's Land, passes across the western part of the Australian continent, and divides, in the Indian Archipelago, into two branches; one crossing the Indian Sea, Asia, Hindostan, Persia, Western Siberia, Lapland, and the Northern Sea; the other, taking a more northern course, traversing China, Chinese Tartary, and Eastern Siberia, whence it loses itself in the Arctic Seas. The whole earth seems by this line divided into two great hemispheres; one embracing Europe, Africa, and the western part of Asia, the other comprising nearly the whole of the American continent, the entire Pacific Ocean, and a portion of Eastern Asia. In the first hemisphere, the deviation of the compass is to the west; in the second, it is to the east. The best map of this kind has lately been published by Hansteen, Professor of Natural Philosophy, in Christiana, Norway.

§ 385. *Variation of the Compass at the same Place.* The most remarkable phenomenon accompanying the variation of the compass, is that *the deviation from the north is not always the same at the same place.* The western deviations increase, until they amount to about 19 degrees; they then diminish, until they become zero, finally deviate to the east, until a certain maximum, whence they recede again to the westward.

The line of no deviation, which now passes through America, went, in the seventeenth century, through Europe. The successive but slow deviation of the compass to the westward and eastward, resembles, in some respects, the oscillations of a large pendulum. Its laws, however, are far from being satisfactorily determined, and will probably need centuries of observation and experiment before they can be relied upon.

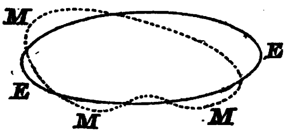
§ 386. *Daily Variation of the Needle.* Another remarkable phenomenon, which deserves to be noticed, is the daily variation of the magnetic needle, at one and the same place. In the forenoon, the magnetic needle moves slowly westward, but returns, during the whole of the remaining time, with a slow easterly motion.

This gradual motion of the compass was first discovered by Graham, in 1722. Wargerlin and Canton have made similar experiments, and have shown that heat has a considerable influence upon this motion. For this experiment very long and nice needles must be used; otherwise the motion of the needle will escape observation.

§ 387. *Dip of the Magnetic Needle.* The dip of the magnetic needle, like its variation, differs in different parts of the globe. As a general rule, which, however, is not without exceptions, we may say, it diminishes near the equator, and increases towards the poles, until, finally, at the poles themselves, the needle is perpendicular to the horizon. Those places at which there is no dip—those, namely, where the needle is perfectly horizontal—are in a line which encircles the earth, and is, on that account, called the *magnetic equator*.

§ 388. The magnetic equator does not coincide with the equator of the earth, but may be considered as a great circle, inclined to the earth's equator, at an angle of about 12 degrees. It cuts the terrestrial equator in four points, assuming somewhat the shape represented in the annexed figure, where the line EE denotes the terrestrial, and MMM the magnetic equator.

Fig. 188.



MAGNETISM OF THE EARTH.

§ 389. To explain the above-described phenomena of the magnetic needle, many philosophers of eminence (among whom are Kepler, Hadley, Euler, Bernouilli, Tobias Mayer, &c.) considered our whole globe as one great magnet, because it operates upon the magnetic needle, as one magnet does upon another.

To illustrate familiarly the operations of terrestrial magnetism, draw a circle upon a board, placed horizontally, and provide its centre with a small magnet. A small magnetic needle, carried

round its circumference, will assume nearly the same situation with regard to the circle, as an inclined magnetic needle does to the earth.

§ 390. It is neither necessary to suppose in theory, nor is it at all probable in reality, that a fixed, limited magnet exists in the centre of the earth, which causes the magnetic phenomena. It is very probable, on the contrary, that there are large masses of magnets scattered in the interior of our globe, whose axes and poles must, on account of the common law of magnetic attraction (see § 369), be nearly parallel to each other, by which means their united virtue is similar to that of a single magnetic bar.

The combined effect of all these masses must always be more or less influenced by the locality of the place.* This is the reason why the variations of the compass appear more irregular the farther we carry our research, and the more accurate the instruments are which are employed for that purpose.

§ 391. If our earth contains large magnetic masses in its centre, then it may be easily conceived, that all the iron in their vicinity must, in course of time, become itself magnetic, which would naturally enough explain the successive changes in the variation and inclination of the magnetic needle.

This is the way in which Tobias Mayer, Professor of Natural Philosophy in Gottingen, explains the variation and changes in the dip of the magnetic needle; which, according to his supposition, must continue, until all the iron which our globe contains is converted into magnet.

§ 392. *Effects of Terrestrial Magnetism.* Among the effects of terrestrial magnetism, we must count the fact, that iron bars become magnetic, without using any other means than exposing them to the atmosphere, in the direction of the dip of the needle. The magnetism thus acquired is, like that produced by induction, of short duration.

Iron instruments may become magnetic, also, by a variety of other means, such as filing, boring, cutting, sawing, hammering, &c. This explains, in some measure, the magnetism acquired

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* This is so far true, that the experiments with a magnetic needle, made in a room or building, seldom agree with those made in the open atmosphere.

by tools used for such purposes, the magnetism of pokers, tongs, and other utensils, which remain for a long time in a vertical position, &c.

INTENSITY OF MAGNETISM.

§ 393. When the magnetic needle is brought out of its natural direction, and let free again, it will vibrate in a manner similar to the oscillations of a pendulum, until it has again assumed its original position. The velocity of these vibrations furnishes us with a correct means of estimating the intensity of the magnetic force, as the oscillations of the pendulum are the only safe means of calculating the velocity of falling bodies, and the diminution of gravity on the equator.

La Place has proved, mathematically, that the whole theory of the pendulum not only perfectly applies to the vibrations of the magnetic needle, but also that the intensities of the magnetic power, in two different places, are in proportion to the squares of the number of vibrations which the needle makes in each of these places. Hereupon he has founded a method of finding the dip of the magnetic needle, by the mere observation of its vibrations.

§ 394. Another remarkable fact, strongly corroborating the hypothesis of terrestrial magnetism, results from the observations of Alexander von Humboldt. He found that the magnetic power is stronger on the equator, and diminishes, without interruption, as we proceed to the south or north of it.

From the same observations, it appears, also, that the *intensity* of the magnetism is far less subjected to local disturbances than the dip of the needle.

MODERN DISCOVERIES IN MAGNETISM.

§ 395. *Facts relative to the Theory of Magnetism.* The intimate relation of magnetism to electricity and heat has long ago fixed the attention of philosophers: modern

discoveries have put the identity of electricity and magnetism almost beyond a doubt.

The following facts will serve to establish the truth of this assertion :—

1. The conducting wires of the voltaic pile produce deviations in the magnetic needle.*

2. The electricity of the conducting wire imparts permanent magnetism to a steel needle.

3. Magnetism can be imparted, also, by common electricity, by means of an electric spark.

Arago and Savary found that the magnetism communicated in this manner to a needle, does not increase with the *number* of sparks, and that its maximum depended on the quality of the steel.

§ 396. *Influence of Heat.* The influence of *heat* upon magnetism has already been spoken of. We will now mention the remarkable experiments first made on that subject by Prof. Seebeck, in 1822.† If a piece of bismuth is connected with a piece of brass or copper, so that the whole forms a ring, and one end of the bismuth is suddenly heated, then a magnetic needle, in its vicinity, will deviate from its direction in the same manner as when affected by the zinc pole of a voltaic battery. If, instead of bismuth, antimonium be taken, then the result will be exactly the reverse; that is, the needle will deviate in the opposite direction.

Bismuth and antimonium are not the only metals which, combined with copper, and then heated, produce deviations of the magnetic needle. They produce this effect only in a greater degree.

§ 397. *Influence of Light.* It remains for us to notice the influence of light on the developement of magnetism. Marochini, in Rome, found that steel needles became magnetic when exposed for a length of time to the violet rays of the prismatic spectrum. Lady Somerville, in London, and Baumgärtner, in Germany, made similar experiments, and obtained the same result.

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* This discovery was made in 1820, by Prof. Aerstädt.

† Gilbert's Annals of Natural Philosophy, Vol. LXXII.

The red, orange, and yellow rays are without effect; the green, blue, and violet rays produce magnetic polarity; green the least, violet the most. The needle must, for this purpose, be half covered, and exposed, for at least two hours, to the influence of the rays. In the focus of a burning-glass the same result is obtained in 20 minutes. The part which is exposed to the violet rays becomes the north pole. The light of the moon or of a lamp produces no such effects.

RECAPITULATION.

Of Magnetism.

[§ 364.] What peculiar property is possessed by certain pieces of black iron oxide? What are these pieces called? Can the power of attracting iron be communicated to other iron or steel? What is a piece of iron or steel, which has thus received the power of a magnet, called?

[§ 365.] Are there, besides iron, any other metals which participate in the magnetic properties? *What are all bodies, according to modern discoveries, susceptible of?*

In what parts of the world are native magnets found?

A.—*Relation of Native Magnets to Unmagnetic Iron.*

[§ 366.] What metals adhere to native magnet with considerable force?

How can this power be measured? Does this power depend on the size of the magnet? Is it always the same in one and the same magnet?

[§ 367.] Does the magnetic power operate in all points of the surface of a magnet with equal intensity? How many places are there, in which its attractive powers are greatest? What are these places called?

How can they be made visible? What position will a thin piece of iron have at the poles of the magnet? What position will it have in the middle? What, in any other place of its surface?

[§ 368.] Is the magnetic attraction increased or diminished, when both poles are made to operate at the same time?

What shape is, on this account, generally given to artificial magnets?

[§ 369.] Is the attractive power of magnet manifest only in contact, or does it operate, also, at considerable distances? What general law does, in this respect, apply also to the magnet?

[§ 370.] What takes place when a native magnet is placed under a plate of glass, wood, pasteboard, or even metal, which is thinly covered with iron filings?

What does this experiment prove?

[§ 371.] How may the power of a magnet be preserved, or even increased?

Does oxidation increase or diminish the attractive power of magnet? What effect has heat upon it?

B.—*Relation of a Magnet to itself, and to another Magnet.*

[§ 372.] When a magnet is so situated that it can freely move in a horizontal position, in what determined direction does it always place itself? What is this wonderful property of the magnet called?

What all-important instrument is constructed upon this property of the magnet? Was this property known to the ancients?

[§ 373.] Does the attraction which exists between a magnet and unmagnetic iron, exist also between two magnets? *What law is there with regard to the respective poles of two magnets?*

How can this law be exhibited? What are the two poles which mutually attract each other called? What are those poles called, which seem to repel each other?

Imparting of Magnetism.

[§ 374.] How many different methods are there of making artificial magnets? What are they?

[§ 375.] Explain the method of *single touch:* (1.)* With one magnet only. (2.) Explain the same operation when two magnets are employed. (3.) What is the most effectual way of communicating magnetism by the single touch?

[§ 376.] Explain the method by *double touch.*

[§ 377.] Explain the method by *percussion.*

Why is it best (in the method by percussion) to hammer the steel bars upon soft iron or steel, in preference to wood, or any other substance?

[§ 378.] *What is the general law observed in making artificial magnets, by any method whatever?*

Which is easier magnetized, soft iron, or steel? In which is the magnetic power more permanent?

[§ 379.] Does the magnet, which is employed in magnetizing a steel bar, lose much of its own power? Can one and the same magnet be employed for magnetizing several bars? What is the name of an apparatus formed by the combination of a number of such bars?

[§ 380.] In what state is a piece of iron, as long as it is attached to a magnet? What is it, in this state, said to be? Does the magnetic power, thus acquired, continue after the magnet is removed from it?

[§ 381.] What is the law of magnetic attraction similar to? What pole does the south pole of a magnet excite in the end of an iron bar, which is in its immediate neighborhood? What, in that end which is most remote from it? What state of magnetism, therefore, does each pole communicate to the neighboring iron?

[§ 382.] What inference have some philosophers drawn from the similarity between the laws of electricity and magnetism?

What did Æpinus suppose all magnetic phenomena to proceed from? How, then, did he account for the magnetic phenomena? How do Wilcke and Brugman explain the magnetic phenomena?

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* The signs (1), (2), (3), refer to §375, 1st, 2d and 3d.

Of the Variation and Dip of the Magnetic Needle.

[§ 383.] When an unmagnetic iron needle is poised, in its centre, upon a sharp point, so that its position is perfectly horizontal, and it is afterwards magnetized, what position will it then, in most places, assume? *What is the deviation from due north called? What, the inclination to the horizon?*

[§ 384.] How many degrees westward of due north does the north pole of the compass deviate in England, and throughout Europe? Do these deviations remain always the same? What is the line in which the compass points exactly north called? What are the deviations beyond this line?

What does the line of no deviation seem to form? Through what countries does it pass? Into what is the whole earth by this line divided? Which way does the compass deviate, in the first hemisphere? Which, in the second?

[§ 385.] *What is the most remarkable phenomenon accompanying the variation of the compass?* How far do the western deviations increase? When do they begin to diminish? Which way do they increase after becoming zero?

Through what part of the world did the line of no deviation go in the 17th century? What are the successive, but slow deviations of the compass to the westward and eastward, similar to?

[§ 386.] What other remarkable phenomenon deserves to be noticed? What is the diurnal motion of the magnetic needle?

By whom was this gradual motion of the compass first discovered? What agent has a powerful influence on this motion? What kind of needles must be used for this experiment?

[§ 387.] Is the dip of the magnetic needle the same in all parts of the globe? What general rule can you give respecting the dip of the magnetic needle? In what line are those places at which there is no dip situated? What is this line called?

[§ 388.] Does the magnetic equator coincide with the equator of the earth? How, then, is it inclined to the earth's equator? In how many points does it cut the terrestrial equator?

Magnetism of the Earth.

[§ 389.] What did many philosophers of eminence consider our whole globe to be? Why?

How can you illustrate the operation of terrestrial magnetism?

[§ 390.] Is it probable that a fixed, limited magnet exists in the centre of the earth? How, then, do you account for the magnetism of the earth?

If there are large masses of magnet scattered in the interior of our globe, by what will their combined effect be more or less influenced? What does this explain?

[§ 391.] If our earth contains large magnetic masses in its centre, what must become of all the iron in their vicinity? What phenomena would, by this supposition, be explained?

[§ 392.] What important fact must be ascribed to the operation of terrestrial magnetism? Is the magnetic power acquired through the influence of terrestrial magnetism permanent?

By what other means can iron instruments become magnetic? What phenomena does this explain?

Intensity of Magnetism.

[§ 393.] In what manner does a magnetic needle move, when it is brought out of its natural position, and then let free again? What are we able to estimate by the velocity of these vibrations?

What important law did La Place discover respecting the intensities of the magnetic power in two different places?

[§ 394.] What other remarkable fact, strongly corroborating the hypothesis of terrestrial magnetism, results from the observations of Alexander von Humboldt?

Is the intensity of magnetism subjected to the same local disturbances as the magnetic needle?

Modern Discoveries in Magnetism.

[§ 395.] What intimate connection is, by modern dis-

coveries, proved to exist between electricity and magnetism? What facts can you adduce to establish the truth of this assertion?

Does the magnetism, imparted to a needle by electric sparks, increase with the number of sparks? On what, then, does its maximum depend?

[§ 396.] What remarkable experiment was first made by Prof. Seebeck, on the subject of the influence of heat upon magnetism? If, in the experiment you have just described, antimony be substituted for bismuth, what results will then be obtained?

Are bismuth and antimonium the only metals which, combined with copper, and then heated, produce deviations of the magnetic needle?

[§ 397.] What influence of light on magnetism did Marochini, in Rome, first discover? Were similar results obtained by any other person? By whom?

What rays are without magnetic effect? What rays produce magnetic polarity? Which rays produce the least, and which the greatest polarity? In what manner must the needles be prepared, and how long must they remain exposed to the influence of the rays, before they exhibit magnetic polarity? In how many minutes is the same result obtained in the focus of a burning-glass? What part of the needle becomes the north pole? Does the light of the moon or of a lamp produce similar effects?

TABLE I.

Specific Gravities of Bodies compared with Distilled Water.

Alcohol, highly rectified	0.809
Blood	1.053
Camphor	0.988
Chalk	2.657
Diamond (Oriental)	3.521
" (Brazilian)	3.444
Ether	0.866
Flint	2.582
Crown Glass	2.520
Flint Glass, from 2.760 to	3.000
Gunpowder, loose	0.836
" solid	1.745
Indigo	1.009
Isinglass	1.111
Ivory	1.825
Limestone, from 2.386 to	3.000
Marble	2.716

Metals.

Antimony	6.702
Arsenic	5.763
Bismuth	9.880
Brass, from 7.824 to	8.396
Cobalt	8.600
Copper	8.900
Gold, cast	19.25
Gold, hammered	19.35
Iron, cast	7.248
Iron, bar-hammered	7.778
Lead	11.35
Manganese	8.000
Mercury, at 60° Fahrenheit	13.58
Nickel, cast	8.279
Platinum	21.47
Silver	10.47
" hammered	10.51
Steel, soft	7.833
" hardened	7.840
Tellurium, from 5.700 to	6.115
Tin	7.291
Zinc, from 6.900 to	7.191

Wood.

Apple-tree	0.793
Beech	0.852
Brazilian, Red	1.031
Cedar, American	0.561
Cherry-tree	0.715
Cork	0.240
Ebony, American	1.331
Elm	0.671
Lignum Vitæ	1.333
Mahogany	1.063
Maple	0.750
Oak	1.170
Olive-tree	0.927
Orange-tree	0.705
Pear-tree	0.166
Poplar	0.383
Vine	1.327
Walnut	0.681
Willow	0.585
Wood-stone, from 2.045 to	2.675

TABLE II.

Exhibiting the Specific Caloric contained in some Substances, compared with the Quantity of Caloric contained in an equal Weight of Water.

Gases and Liquids.		*Metals.*	
Oxygen	0.2361	Bismuth	0.0288
Azote	0.2754	Lead	0.0298
Water	1.0000	Gold	0.0298
Air	0.2669	Platinum	0.0314
Hydrogen Gas	3.2936	Tin	0.0514
Carbonic Acid	0.2210	Silver	0.0557
Aqueous Vapor	0.8470	Zinc	0.0927
		Tellurium	0.0912
		Copper	0.0949
		Nickel	0.1005
		Iron	0.1100
		Cobalt	0.1498
		Sulphur	0.1880

TABLE III.

Boiling Points.

Ether	100° Fahr.
Alcohol	$173\frac{1}{2}$
Nitric Acid	210
Water	212
Sea Salt (solution)	$224\frac{1}{3}$
Muriate of Lime	230
Muriatic Acid	232
Nitric Acid	240
Oil of Turpentine	316
Linseed Oil	640
Mercury	656

TABLE IV.

Exhibiting the Degree of Temperature at which various Liquids congeal or freeze.

Sulphuric Ether	— 46°
Nitric Acid	— 45.5
Sulphuric Acid	— 45
Mercury	— 39
Brandy	— 7
Pure Prussic Acid	+ 4
Strong Wines	+ 20
Oil of Turpentine	+ 14
Blood	+ 25
Vinegar	+ 28
Milk	+ 30
Water	+ 30

TABLE V.

Showing the Refractive Power of several Substances; that of Atmospheric Air being taken for Unity.

Diamond	2.755	Amber	1.547
Melted Sulphur	2.148	Oil of Tobacco	1.547
Sulphate of Lead	1.925	Plate Glass	1.514
Sapphire, blue	1.794	Colophony	1.543
" white	1.768	Beeswax	1.542
Glass	1.732	Gum of Tragacanth	1.520
Topaz, Brazil	1.640	Gum Arabic	1.502
Mother of Pearl	1.653	Oil of Caraway-seed	1.491
Oil of Cassia	1.641	Castor Oil	1.490
Castor	1.626	Camphor	1.487
Tortoise-shell	1.591	Oil of Turpentine	1.475
Horn	1.565	" Lavender	1.462
Resin	1.559	" Camomile	1.457
Turpentine	1.557	Fluor Spar	1.434

Alcohol	1.372	Hydrogen	0.470
White of Eggs	1.361	Azote	1.020
Ether	1.358	Chlorine	2.623
Crystalline Lens of the Human Eye	1.384	Nitrous Gas	1.030
Ice	1.308	Oxide of Carbon	1.157
Atmospheric Air	1.000	Carbonic Acid	1.526
Oxygen	0.924	Muriatic Ether	3.720
		Sulphurous Acid	2.260

THE END.